

Sand Creek Downstream of Colfax Avenue Major Drainageway Plan
Baseline Hydrology Report
May 2018

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URBAN DRAINAGE AND FLOOD CONTROL DISTRICT

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May 31, 2018

Ms. Morgan Lynch, P.E., CFM
Urban Drainage and Flood Control District
Watershed Services Manager
2480 West 26th Avenue, Suite 156-B
Denver, CO 80211

RE: Sand Creek MDP and FHAD

Dear Ms. Lynch:

ICON Engineering, Inc. is pleased to submit the Baseline Hydrology chapter of the Sand Creek Downstream of Colfax Avenue Major Drainageway Plan. We appreciate the comments provided on the Draft Baseline Hydrology Report and further input regarding model sensitivity and land use parameters. This submittal incorporates this feedback received and support information reconciled through the District, project stakeholders, Kevin Stewart, and Dr. James Guo.

We would like to acknowledge the projects team's assistance in the preparation of this study. This report could not have been prepared without input from yourself, and other stakeholders.

We believe that this report will provide a solid frame work for the continuing phases of this project.

Sincerely,

ICON ENGINEERING, Inc.

Craig D. Jacobson, P.E., CFM
Principal, Project Manager

Jeremy K. Deischer, P.E.
Project Engineer

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1.0 INTRODUCTION

1.1 AUTHORIZATION

This report was authorized by the Urban Drainage and Flood Control District (UDFCD) under joint sponsorship with City of Aurora, City of Commerce City, and City and County of Denver under the August 2017 agreement regarding "Major Drainageway Plan and Flood Hazard Area Delineation for Sand Creek Downstream of Colfax Avenue", Agreement No. 17-08.09.

1.2 PURPOSE AND SCOPE

The purpose of this study is to provide updated hydrologic and hydraulic information for Sand Creek downstream of Colfax Avenue. In addition, Sponsors indicated other goals and objectives for the study:

- Reduce the flood risk
- Improve the ecological function of the stream corridor.
- Create a stable channel that seamlessly integrates with open space and parks to create more of an amenity than strictly a conveyance system.
- Evaluate roadway crossings
- Evaluate the possible aggradation of the soil cement channel.
- Evaluate the Zone X with reduced flood risk due to levee near Chambers Road.
- Evaluate possible spill of Sable Ditch into Sand Creek.
- Update the floodplain delineation
- Try to improve Sand Creek as it is currently on the State of Colorado's 303D, impaired waters, list.

Throughout the study area several tributary drainageways discharge into Sand Creek that have been previously studied for UDFCD. The main goal of the hydrology update of the project is to convert the drainageways into one model. More specifically, the following is a summary of the scope of work for the hydrologic portion of the study:

- Collect existing information including previous Major Drainageway Plans, Outfall System Plans, and Flood Hazard Area Delineation for tributaries to Sand Creek;
- Update existing studies to utilize Colorado Urban Hydrograph Procedure (CUHP) v.2.0 with a 6-hour rainfall distribution for basin hydrology and EPA SWMM 5.1.012 for basin routing;
- Delineate subwatershed boundaries for areas tributary to Sand Creek not within an existing UDFCD study area;
- Develop hydrology models using EPA SWMM 5.1.012 for existing and future watershed conditions for the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year design storms. Basin runoff will be modeled using CUHP v.2.0.

1.3 PLANNING PROCESS

Progress meetings were held at various stages throughout the project. A summary of these meetings can be found below. Minutes from the progress meetings can be found in Appendix A.

- August 22, 2017: Kickoff Meeting
- October 30, 2017: Baseline Hydrology Progress Meeting
- December 19, 2017: Baseline Hydrology Progress Meeting

1.4 MAPPING AND SURVEYS

Project mapping was based on Federal Emergency Management Agency (FEMA) 2013 Post-flood LiDAR. The Lidar data was converted into one-foot interval contours for the study area.

The LiDAR mapping has the following attributes.

- Name: 2013 South Platte River Flood Area 1
- Collection Date: Fall 2013 – Spring 2014
- Vertical Accuracy: 9.25 cm RMSE
- Point Spacing: 0.7 m
- Vertical Datum: NAVD88
- Horizontal Datum: NAD83

Survey was collected by Wilson & Company in October 2017 for crossing structures and drop structures within the project area. This survey was used to supplement the LiDAR data.

1.5 DATA COLLECTION

Numerous previous reports were collected and reviewed as part of this study. A summary of these reports can be found below:

Table 1-1: Data Collected

Report Name	Author	Date
Sand Creek FHAD	UDFCD	1977
Sand Creek MDP	Simons, Li & Associates, Inc.	1984
Murphy Creek FHAD	Moser & Associates	2006
Baranmor Ditch Watershed OSP	Olsson Associates	2010
East Toll Gate Creek (Upper) FHAD	J3 Engineering Consultants	2010
Park Hill (North of Smith Road) Drainage OSP	Enginuity Engineering Solutions	2012
Peoria - Fitzsimons Stormwater Outfall Preliminary Drainage Report	City of Aurora - Water Department	2012
Sand Creek Colfax to Yale FHAD	Matrix Design Group	2012
Sand Creek Colfax to Yale MDP	Matrix Design Group	2013
Toll Gate Creek & East Toll Gate Creek FHAD	J3 Engineering Consultants	2013
West Toll Gate Creek FHAD	Michael Baker Jr. & Enginuity Engineering Solutions	2013
Amendment to Baranmor Ditch Watershed OSP	ICON Engineering, Inc.	2014
Toll Gate Creek & East Toll Gate Creek MDP	J3 Engineering Consultants	2014
Westerly Creek (Upstream of Dam) MDP	CH2M Hill	2015
Sand Creek Right Bank OSP	Merrick & Company	2016
Lower Westerly Creek FHAD (Hydrology)	Matrix Design Group	2017
Original Aurora	Calibre Engineering	2018

1.6 ACKNOWLEDGEMENTS

This report was prepared with cooperation of UDFCD, City of Aurora, City of Commerce City, and the City of Aurora. The representatives who were involved with this study are listed in Table 1-2, below.

Table 1-2: Project Team

Name	Organization	Title
Shea Thomas	Urban Drainage and Flood Control District	Watershed Services Manager
Morgan Lynch	Urban Drainage and Flood Control District	Project Manager
Curtis Bish	City of Aurora - PROS	Principal Planner
Bill McCormick	City of Aurora - Public Works	Associate City Engineer
Craig Perl	City of Aurora - Public Works	Principal Engineer
Sarah Young	City of Aurora - Water	Planning Services Manager
Jon Villines	City of Aurora - Water	Design Engineer
Andrew Pihaly	City of Commerce City	City Engineer
Cincere Eades	City of Denver - Parks and Rec	Parks Planner
Jeremy Hamer	City of Denver - Floodplain	Senior Engineer / Floodplain Administrator
David Morrisey	City of Denver - Floodplain	Engineer
Sam Pavone	City of Denver - Wastewater Capital Projects Management	Senior Engineer
Craig Jacobson	ICON Engineering	Project Manager
Jaclyn Michaelsen	ICON Engineering	Project Engineer
Jeremy Deischer	ICON Engineering	Project Engineer

2.0 STUDY AREA DESCRIPTION

2.1.1 PROJECT AREA

The Sand Creek Basin has a drainage area of approximately 181 square miles, spanning multiple jurisdictions. The Sand Creek Basin is comprised of the following subwatersheds: Coal Creek, Senac Creek, Murphy Creek, Toll Gate Creek, Baranmor Ditch, Westerly Creek, and Park Hill. The area for this study begins at Colfax Avenue and terminates at the confluence with the South Platte River. The study area includes the communities of the City of Aurora, City of Commerce City, and the City and County of Denver. Nearly 14 miles of Sand Creek Regional Greenway multi-use trails follow the stream corridor. Refer to Figure 2-2 for the map of key features within the study area and Figure 2-3 for a map of the entire Sand Creek Basin.

From the confluence with the South Platte River, Sand Creek spans Commerce City to just downstream of Quebec Street. Immediately upstream of the confluence with the South Platte River, along the left bank of Sand Creek, are the Metro Wastewater Reclamation District and the Suncor Energy facilities. The Burlington Ditch also crosses Sand Creek approximately 1,500 feet upstream of the confluence.

Sand Creek enters City and County of Denver jurisdiction upstream of Quebec Street and extends northwest to the Bluff Lake Nature Center, located between Havana Street and Peoria Street. Sand Creek crosses the Regional Transportation District (RTD) Light Rail A-line and Union Pacific Railroad (UPRR) just upstream of the I-70 crossing. The Denver County Jail is also located along the right bank of Sand Creek just upstream of Havana Street.

Upstream of the Bluff Lake Nature Center, Sand Creek enters the City of Aurora and confluences with Baranmor Ditch. Toll Gate Creek joins Sand Creek upstream of Peoria Street in Sand Creek Park.

Elevations within the study area range between 5,456 feet, at Colfax Avenue, to approximately 5,100 feet at the confluence with the South Platte River. The average slope of the watershed is approximately 0.5 percent. The Sand Creek Basin is approximately 35 miles long and spans 8 miles at its widest point. The majority of the Sand Creek watershed within the study area, downstream of Colfax Avenue, is developed. Development throughout the study area primarily consists of residential, commercial, and industrial land uses with some open space area surrounding the stream corridor.

The basin is comprised of multiple hydrologic soil types as defined by the Natural Resources Conservation Service (NRCS) (Reference 10). The study area contains Type A, Type B and Type C soils. Soil information for subwatersheds within the City and County of Denver were obtained from subwatersheds within the City and County of Denver Storm Drainage Master Plan (Reference 4). The distribution of soil through the study area can be found on the interactive map in Appendix B.

The Urban Drainage and Flood Control District re-use number for Sand Creek is 4400. Re-use numbers for major tributaries of Sand Creek are: Coal Creek (4410), Senac Creek (4411), Murphy Creek (4409), East Toll Gate Creek (4408), West Toll Gate Creek (4405), Westerly Creek (4401), and Park Hill (4500).

2.1.2 LAND USE

Existing land use varies throughout the study area. At the upstream end of the study area in the City of Aurora land use consists of residential, commercial, and industrial development. Through the City and County of Denver, existing land use includes; open space, residential, commercial mixed use and industrial development. In Commerce City, downstream of Quebec Street, existing land use is predominately industrial. Downstream of Colfax Avenue, future land use projections reflect existing land uses for the majority of the study area. Upstream of Colfax there are areas for future development, further described in the Sand Creek Colfax to Yale FHAD (Reference 9).

The existing and future conditions land use map can be found on the interactive pdf map found in Appendix B.

Existing imperviousness for the City of Denver and City of Aurora was determined using existing planimetric data provided by each jurisdiction. Planimetric data included land use designations for buildings, driveways, parking, paved surfaces, and sidewalks. Impervious values for each land use designation were assigned using Table 6-3 of USDCM (Reference 1) and can be found in Table 2-1.

Existing imperviousness for Commerce City was determined using the National Land Cover Database (NLCD). The NLCD was obtained from the Multi-Resolution Land Characteristics Consortium (MRLC) website. The NLCD created by MRLC, last updated in 2011, is a 16-class land cover classification applied across the United States at a spatial resolution of 30 meters (Reference 3). No modifications were made to the NLCD dataset.

Future conditions land use projections were determined from zoning data obtained from each jurisdiction. Data was obtained from City of Aurora and City of Denver websites. Commerce City zoning data was digitized from zoning maps obtained from their website. Impervious values for each zoning classifications were selected using values from multiple sources. Values within the City of Aurora were obtained from the USDCM (Reference 1) and the Original Aurora Stormwater Master Plan study. Future impervious values for the City of Denver were carried forward from the City and County of Denver Storm Drainage Master Plan (Reference 4). Future land use percent impervious values for each jurisdiction can be found in Table 2-2.

Existing and future conditions land use can be found in the interactive map located in Appendix B.

Table 2-1: Existing Land Use[1]

City of Aurora				City of Denver			
Land Use Designation	Impervious %	Percent of Jurisdiction	Percent of Basin	Land Use Designation	Impervious %	Percent of Jurisdiction	Percent of Basin
Pervious	2	61.6%	14.5%	Pervious	2	50.6%	32.2%
Building	90	12.4%	2.9%	Building	90	17.0%	10.8%
Driveway	100	2.2%	0.5%	Driveway	100	16.0%	10.2%
Parking	100	9.1%	2.2%	Parking	100	13.3%	8.4%
Paving	100	12.3%	2.9%	Sidewalk	100	3.0%	1.9%
Sidewalk	100	2.4%	0.6%				

1 - Existing Land Use for Commerce City was developed using the NLCD

Table 2-2: Future Land Use Table

City of Aurora			
Zoning Designation	Impervious %	Percent of Jurisdiction	Percent of Basin
Open Space	2	10.2%	2.3%
--	--	--	--
--	--	--	--
Residential-Agricultural District	52	2.4%	0.6%
Low Density Single-Family Residential District	55	32.2%	7.3%
Medium Density Single Family Attached Residential District		0.9%	0.2%
Medium Density Residential District		2.9%	2.9%
Mobile Home District		4.7%	1.1%
High Density Multi-Family Residential District	75	3.2%	0.7%
Medium Density Multi-Family Residential District		0.8%	0.2%
Retail Business District	75	3.6%	0.8%
Business and Commercial District		1.2%	0.3%
Light Industrial District	80	4.2%	1.0%
Industrial Office District		21.2%	4.8%
Fitzsimons Boundary Area District (mixed)		3.5%	0.8%
Medium Industrial District	85	2.0%	0.4%
Large Industrial District	90	6.9%	1.6%

City of Denver			
Zoning Designation	Impervious %	Percent of Jurisdiction	Percent of Basin
Open Space - Conservation	2	4.9%	3.0%
Open Space - Conservation[1]	50	5.3%	3.3%
Open Space - Public Parks	10	3.6%	2.2%
--	--	--	--
Residential	52	31.8%	19.9%
--	--	--	--
Commercial Mixed Use	90	27.8%	17.4%
PUD	95	0.3%	0.2%
--	--	--	--
Industrial - Heavy	95	26.4%	16.5%

City of Commerce City			
Zoning Designation	Impervious %	Percent of Jurisdiction	Percentage of Basin
Agricultural	2	1.3%	0.2%
--	--	--	--
--	--	--	--
--	--	--	--
Single-Family Attached Residential	52	3.0%	0.4%
--	--	--	--
General Commercial	90	1.8%	0.3%
Regional Commercial		2.8%	0.4%
Light Intensity Industrial	95	9.1%	1.3%
Industrial Park Storage		13.1%	1.9%
PUD		12.2%	1.8%
Medium Intensity Industrial	95	30.4%	4.4%
Heavy Intensity Industrial	95	26.4%	3.8%

1 - Areas zoned Open Space - Conversation through the I-70 corridor were assigned 50% Impervious to reflect future development

2.1.3 FLOOD HISTORY

The Sand Creek basin has an extensive history of flooding with 10 notable flood events impacting the basin since 1896. Sand Creek has experienced major floods in 1896, 1912, 1917, 1933, 1938, 1948, 1957, 1965, 1973, and most recently in 2013 (Reference 7).

Little information is available for floods prior to 1940 due to the basin being undeveloped. Below is a summary of the information known about past events:

- Resulting damages of the 1948 event exceeded $130,000 with the peak discharge at the mouth of Sand Creek estimated at 10,500 cfs (Reference 7).
- A peak discharge of 25,000 cfs was estimated near Stapleton International Airport during the 1957 event resulting in over $330,000 in damages (Reference 7).
- In June 1965 heavy intense rainfall fell throughout the South Platte River Basin. Rainfall accumulation totals were estimated approximately 14 inches, most of which fell within a few hours. A 1969 report by the U.S. Geological Survey (Reference 6) analyzed the Denver flood of 1965 estimating the peak discharge along Sand Creek to be 18,900 cfs. The discharge was estimated approximately four miles upstream of the mouth. The Denver FIS estimated the discharge below Toll Gate Creek to be 18,900 cfs (Reference 7). Damages from the event are estimated to be approximately $2,517,000 (Reference 7).
- In September 2013 most of the South Platte River experience flooding after extreme rainfall over several days. As much as 12 to 20 inches of rainfall fell throughout the Front Range including the Sand Creek Basin (Reference 5). Severe erosion of channel banks occurred near the mouth of Sand Creek washing out the stream gage in the area. Both the gage near the mouth of Sand Creek and just upstream of the Burlington Ditch recorded a peak discharge of 14,900 cfs, the largest recorded discharge since the gage at the mouth began recording data in 1992 (Reference 5)..

There are three active stream gages within the study area: UDFCD Alert Gage 1803, USGS station 06714360, and 394839104570300. Alert 5 Gage 1803, located in Sand Creek Park just upstream of the confluence with Toll Gate Creek, and has collected streamflow data since 1989. The peak discharge at this gage was estimated to be 4,684 cfs during the September 2013 event.

USGS station 06714360 is located just upstream of the Burlington Ditch. This gage has only been in operation since 2013. USGS station 394839104570300 is located just upstream of the mouth of Sand Creek. This gage has recorded daily streamflow data dating back to 1992.

Much of this gage data has been reviewed and documented by the District or evaluated as part of recent hydrologic updates. As such, the District prepared a memorandum discussing the gage applicability as it relates to this current study. The entirety of the District memorandum is provided in Appendix A. A summary of highlights from the memorandum is provided below:

- USGS station 394839104570300, located just upstream of the mouth with Sand Creek has gage records of 19 years, including a recorded peak flow estimate of 14,900 cfs in September 2013.
- USGS station 06714360 only has a four year period of record and is not considered statistically significant.
- Recently, Wright Water Engineers (WWE) performed a Bulletin 17-B flood frequency analysis for the District as part of the South Platte River Hydrology CLOMR project. This analysis utilized 19 years of record (1993-013). The 100-year discharge was estimated to be 20,080 cfs, with a 95-percent confidence interval from 11,960 cfs to 48,090 cfs.

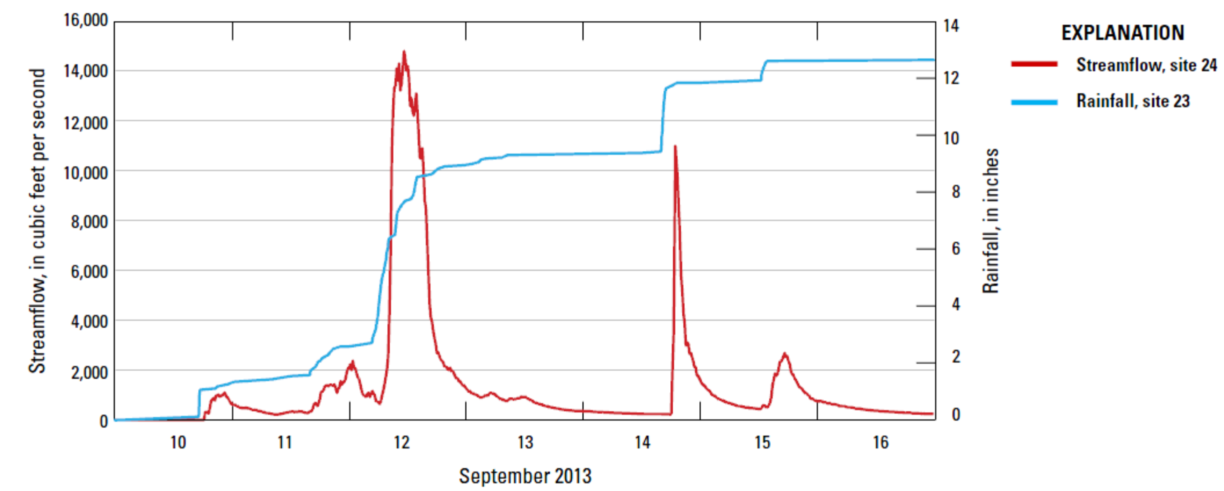
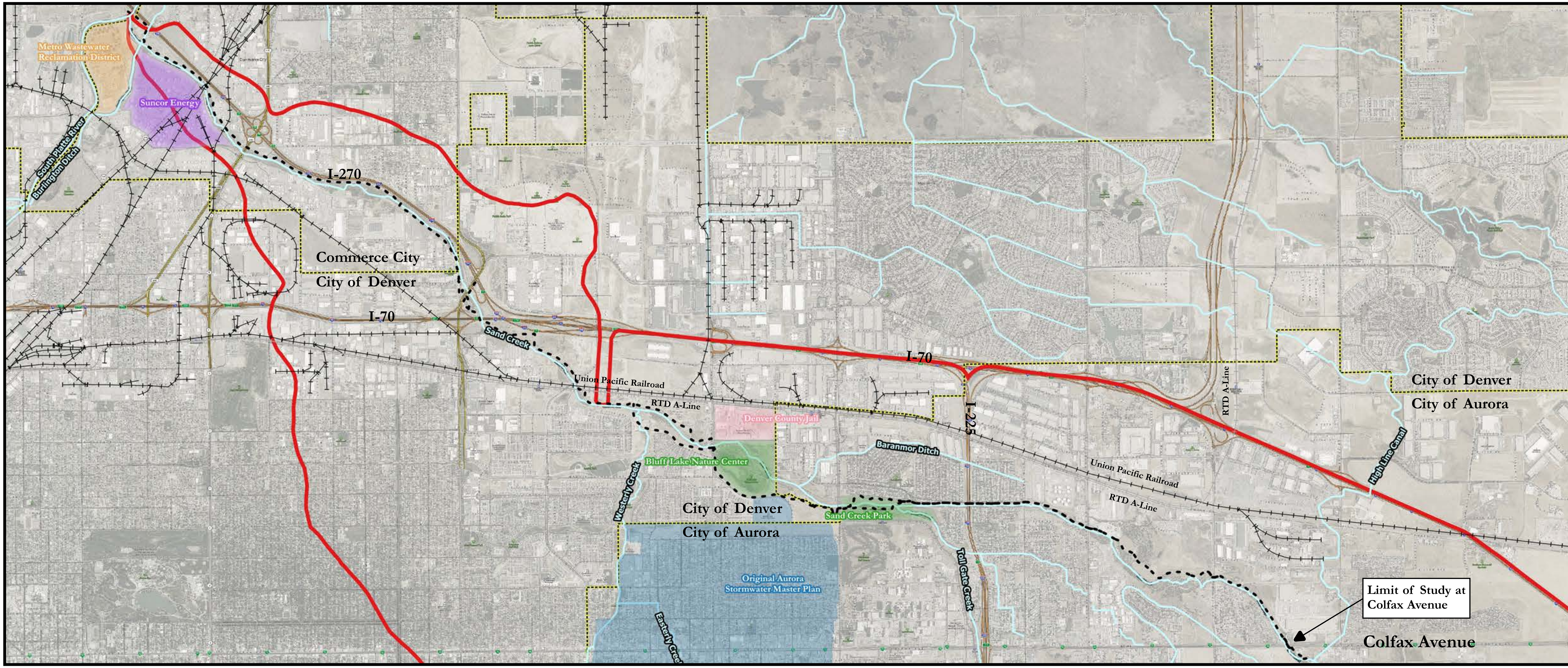


Figure 2-1: USGS Stream Gage upstream of Burlington Ditch from 2013 Storm (Reference 5)



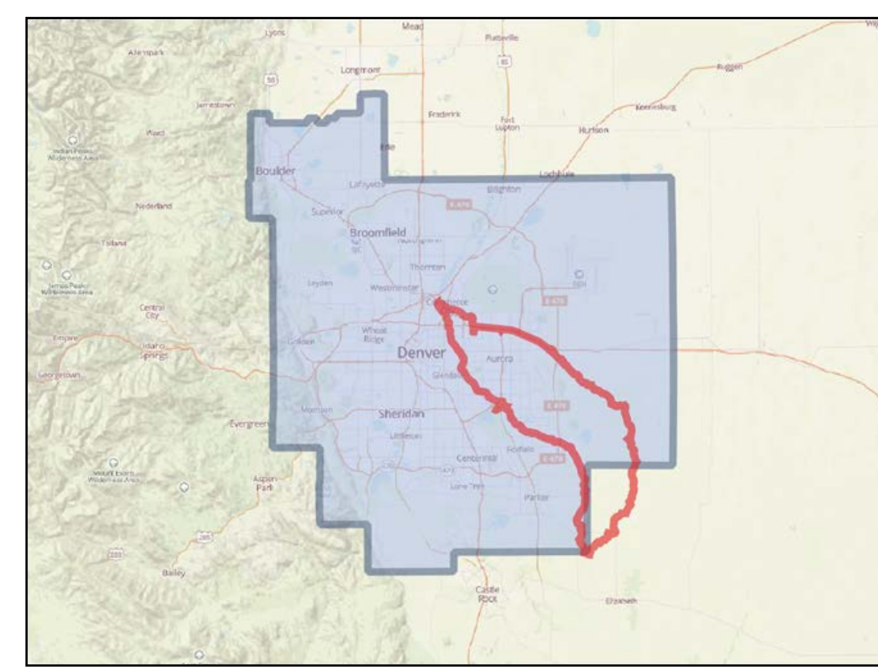
Sand Creek Master Drainage Project

Figure 2-2: Study Area Map

North

0 1 2 3 mi

- Stream Centerline
- RTD Light Rail
- Railroad
- Sand Creek Greenway Trail
- Jurisdictional Boundaries



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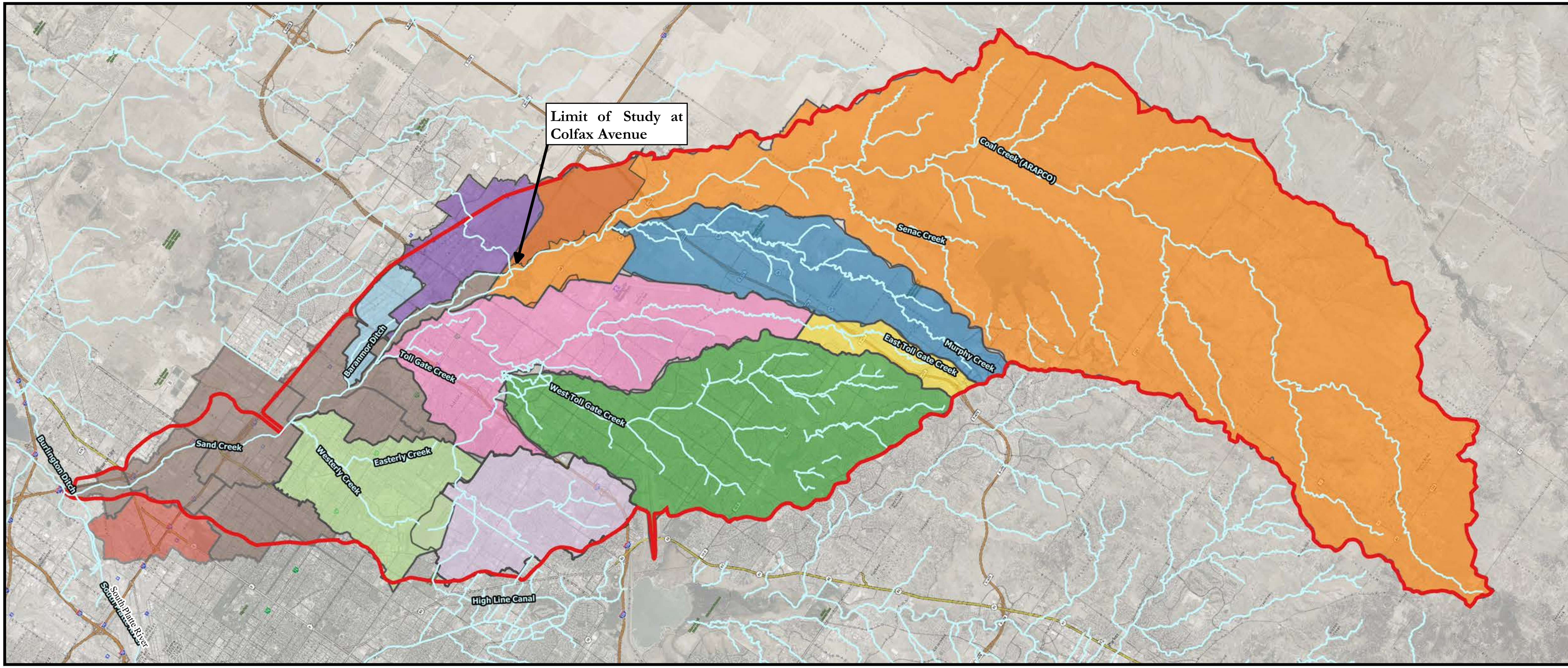


Sand Creek Master Drainage Project

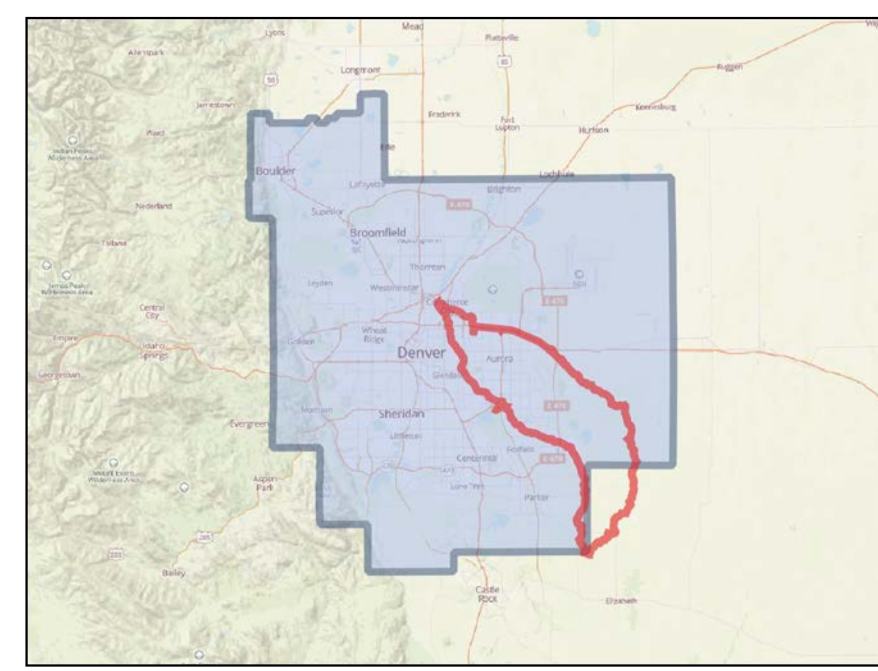
Figure 2-3: Watershed Map

North

0 1 2 3 mi

UDFCD Study Boundaries

- Baranmoor (2010)
- Murphy Creek (2006)
- Park Hill OSP (2012)
- Sand Creek Right Bank Trib (2016)
- Sand Creek - Colfax to Yale (2013)
- Toll Gate Creek East (2014)
- Toll Gate Creek East Upper (2010)
- Toll Gate Creek West (2013)
- Westerly Creek Lower (2016)
- Westerly Creek Upper (2015)
- 2017 Sand Creek MDP
- UDFCD Streams
- Approximate Sand Creek Tributary Area



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3.0 HYDROLOGIC ANALYSIS

3.1 OVERVIEW

A new hydrologic model was prepared for the Sand Creek Basin from Colfax Avenue to the confluence with South Platte River. The model provides updated hydrology for both existing and future conditions for the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year storm frequencies. The Colorado Urban Hydrograph Procedure 2005 version 2.0.0 (CUHP) was used to develop runoff hydrographs for each subwatershed. Subwatershed hydrographs were then routed using the EPA Stormwater Management Model version 5.1.012 (SWMM) to determine discharges at each design point.

Existing UDFCD studies for Sand Creek upstream of Colfax Avenue (2013), Murphy Creek (2006), Toll Gate Creek (2014), Baranmor Ditch (2010), and Westerly Creek (2017) were used as the basis for inflow from each tributary to Sand Creek. No alterations were made to existing subwatershed delineations, basin parameters or hydrograph routing. The CUHP model for each tributary was first converted to CUHP v.2.0 and calibration factors used in the original studies were removed. Rainfall values for each study were then updated to a 6-hour rainfall distribution, as further discussed in Section 3.2. Each CUHP model was executed and routed through the SWMM model developed as part of the previous analysis. Hydrographs at the outfall of each of the SWMM models were extracted for each design frequency and used as inflow hydrographs in the Sand Creek SWMM model. Inflow locations from each tributary can be found in Figure 3-5 and Figure 3-6. The conversion of existing studies is further described in Section 3.3.

Nine additional subwatersheds were delineated for areas tributary to Sand Creek not covered by previous UDFCD studies. More information on the parameters developed for the nine subwatersheds can be found in Section 3.1.

The FFA previously performed by the UDFCD at the mouth of Sand Creek was referenced as a point of calibration for the rainfall runoff modeling using CUHP v2.0 and SWMM. For the calibration effort, inflow hydrographs from tributaries in SWMM, for existing basin development conditions, were delayed to best correlate with timing of the upper watershed hydrographs and FFA results. For the calibration, the inflow hydrograph from the Toll Gate Creek Watershed was delayed by four hours and all other inflow hydrographs were delayed six hours from the start of the design storm. Timing of the Sand Creek Hydrograph, upstream of Colfax Avenue remained unchanged from the initial CUHP/SWMM results. Overall, the resulting 100-year discharge for the existing conditions was computed to be 20,735-cfs, close in comparison to the 20,080 identified by the FFA.

From this calibration, a future conditions hydrologic model was developed reflecting future land use projections. At the Sand Creek mouth, the future conditions 100-year discharge was calculated to be 31,835-cfs, slightly exceeding the current effective Flood Insurance Study (FIS) flood discharges of 30,500-cfs, which was also based on future conditions. Given that the updated future conditions discharge projection is in excess of 30% thirty percent of the existing land use discharge, the existing conditions discharge will be used for developing flood hazard information for future Flood Insurance Rate Map (FIRM) revisions.

3.2 DESIGN RAINFALL

One- and six-hour rainfall depths were obtained from NOAA Atlas 14 Point Precipitation Frequency Data Server for each existing study and locations within the project area. The point precipitation values at each location can be found in Table 3-1. Spatially varying the rainfall throughout the watershed was not deemed necessary after examining the distribution of point precipitation values and the Sand Creek Watershed generally falling within the same one- and six-hour rainfall isopluvial zone. The one- and six-hour rainfall point precipitation value for each design storm frequency can be found in Table 3-2.

Storm duration and Depth Reduction Factors were chosen using Table 5-1 of the Urban Storm Drainage Criteria Manual (USCDM). A six-hour storm duration and depth area reduction factors were applied for the watershed given the area significantly exceeds 15 square miles. Depth Reduction Factors were obtained from Table 5-3 and 5-4 of USDCM and applied for each time step of the rainfall distribution. The Depth Reduction Factors for each design storm can be found in Table 3-3.

Complete rainfall distributions are provided in Appendix B.

3.1 SUBWATERSHED CHARACTERISTICS

Subwatershed characteristics for each basin delineated as part of this study are further described below and can be found in Appendix B.

3.1.1 SUBWATERSHED DELINEATION

Nine subwatersheds were delineated to account for area tributary to Sand Creek but not covered within a previous UDFCD study. The majority of the subwatersheds (eight of nine) are located in the lower portion of the basin, downstream of the confluence with Westerly Creek. Basins 010 and 020 are located in Commerce City at the downstream end of the watershed. Basins 025, 030, 035, 040 are within the City of Denver and follow the general watershed boundaries of Denver's Storm Drainage Master Plan basins 4400-02, 4400-01, 4400-03, and 4400-04, respectively. In the City of Aurora, Basins 050 and 060 were delineated for left bank areas tributary to Sand Creek and generalized the area studied as part of the Original Aurora Stormwater Master Plan. Basin 070 is located upstream of the Toll Gate Creek confluence to Colfax Avenue and accounts for flows directly tributary to Sand Creek not accounted for in previous studies.

Table 3-1: Point Precipitation Rainfall Distribution

Location	NOAA 14 Rainfall (in)	
	1-hr	6-hr
Sand Creek Mouth	2.4	3.51
Sand Creek Centroid	2.44	3.69
Centroid - Sand Creek FHAD (2012)	2.4	3.65
Sand Creek Headwaters	2.36	3.63
Centroid - Baranmor Ditch (2010)	2.42	3.57
Centroid - Toll Gate Creek (2014)	2.43	3.69
Centroid - East Toll Gate Creek (2010)	2.43	3.69
Centroid - West Toll Gate Creek (2013)	2.43	3.69
Centroid - Sand Creek Right Bank (2016)	2.44	3.61
Centroid - Murphy Creek FHAD (2006)	2.46	3.7
Centroid - Westerly Creek MDP (2015)	2.37	3.59

Table 3-2: 1- and 6-hr Rainfall Depth

Design Storm Return Period (Years)	NOAA 14	
	1 Hr Depths (in)	6 Hr Depths (in)
2	0.86	1.36
5	1.14	1.77
10	1.4	2.14
25	1.78	2.7
50	2.1	3.18
100	2.44	3.69
500	3.33	5.03

Table 3-3: Depth Reduction Factor for Rainfall Distribution

Time (min)	Correction Factor (> 75 Square Miles)	
	2-, 5-, 10-yr	25-, 50-, 100-, 500-yr
5	1.00	1.10
10	1.00	1.10
15	0.56	1.10
20	0.35	0.90
25	0.35	0.55
30	0.42	0.55
35	0.89	0.55
40	0.89	0.80
45	1.00	0.95
50	1.00	0.95
55 - 120	1.00	1.15
125-180	1.00	1.25
185-360	1.33	1.13

3.1.1 WATERSHED IMPERVIOUSNESS

Characterizations of subwatershed imperviousness were determined for both existing and future land use conditions. Existing imperviousness for subwatersheds City of Aurora and City of Denver was determined using GIS planimetric data. Planimetric data included land use designations for buildings, driveways, parking, paved surfaces, and sidewalks. Impervious values for each land use designation were assigned using Table 6-3 of USDCM (Reference 1) and can be found in Table 2-1.

Existing imperviousness values for Commerce City was determined using the National Land Cover Database (NLCD). The NLCD created by Multi-Resolution Land Characteristics Consortium, last updated in 2011, is a 16-class land cover classification applied across the United States at a spatial resolution of 30 meters (Reference 3). The NLCD was reviewed and adjusted to reflect any development within the basin since 2011.

Future conditions land use projections were determined from zoning data obtained from each jurisdiction. Impervious values for each Zoning classifications were selected from Table 6-3 of USDCM. These values can be found in Table 2-2.

Imperviousness for each subwatershed was computed with GIS software using the area weighted average of each land use type. Existing impervious in the subwatersheds varied from 27.6 percent to 63.9 percent impervious. Future land use projects the subwatershed imperviousness to vary from 41.8 percent to 76.3 percent.

Impervious values are shown for the watershed on the impervious map in Appendix B.

3.1.2 LENGTH, CENTROID DISTANCE, SLOPE

CUHP parameters such as subwatershed length, distance to centroid, and slopes were derived for each subwatershed using topographic data. Slopes were computed using the length-weighted, corrected average slope from Equation 6-7 and Figure 6-4 (USDCM). These equations can be found in Figure 3-1 and Figure 3-2.

$$S = \left[\frac{L_1 S_1^{0.24} + L_2 S_2^{0.24} + \ldots + L_n S_n^{0.24}}{L_1 + L_2 + L_3 \ldots L_n}\right]^{4.17} \qquad \text{Equation 6-7}$$

Where:

S = weighted basin waterway slopes in ft/ft

$S_1, S_2, \ldots S_n$ = slopes of individual reaches in ft/ft (after adjustments using Figure 6-4)

$L_1, L_2, \ldots L_n$ = lengths of corresponding reaches in ft.

Figure 3-1: Length Weighted, Corrected Average Slope Equation USDCM Equation 6-7 (Reference 1)

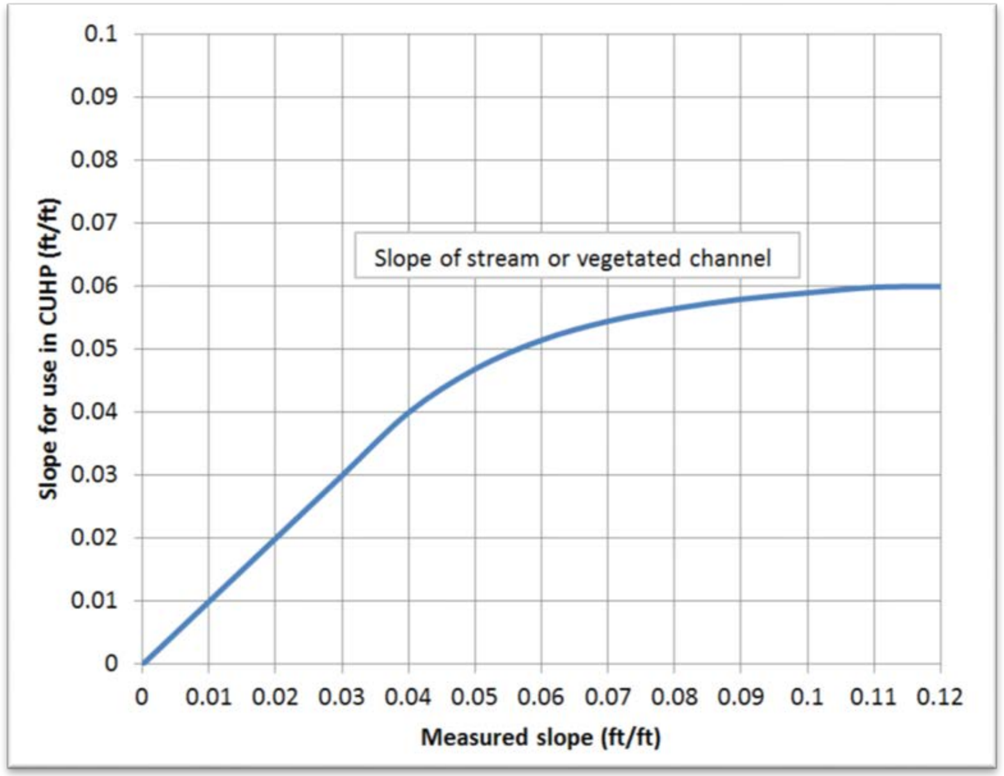


Figure 3-2: Slope correction for streams and vegetated channels
USDCM Figure 6-4 (Reference 1)

3.1.3 DEPRESSION LOSSES

Depression storage loss was determined based on Table 6-6 from the USDCM. A depression loss value of 0.35 was selected for pervious areas and 0.1 for impervious areas. These values can be found in Table 3-4, below.

Table 3-4: Typical depression losses for various land covers - Table 6-6 of USDCM (Reference 1)

Land Cover	Range in Depression Losses	Recommended
Impervious: Large paved areas	0.05 - 0.15	0.1
Impervious: Roofs - flat	0.1 - 3	0.1
Impervious: Roofs - sloped	0.05 - 0.1	0.05
Pervious: Lawn grass	0.2 - 0.5	0.35
Pervious: Wooded areas and open fields	0.2 - 0.6	0.4

3.1.4 INFILTRATION

Soil information for subwatersheds within the City and County of Denver was obtained from subwatersheds within the City and County of Denver Storm Drainage Master Plan (Reference 4).

Soil data for subwatersheds in Aurora and Commerce City was obtained from Natural Resources Conservation Service (NRCS) web soil survey. Each soil classification is assigned a map unit symbol based on the soil characteristics. Map unit symbols categorization is then summarized into one of the four major soil types ranging from Type A representing well-draining soils, to Type D representing poorly-draining soils. These soil types are each assigned parameters for use in Horton's infiltration equation. Horton's infiltration equation initially infiltrates a high amount of runoff early in the storm, eventually decaying to a steady state constant value. Horton's infiltration method was found to provide a balance between simplicity and a reasonable physical description of the infiltration process for CUHP (USDCM).

The subwatersheds delineated as part of this study contain Type A, Type B and Type C soils. The distribution of soil through the study area can be found on the interactive map in Appendix B.

USDCM Table 6-7 provides Horton's infiltration parameters for each soil type. Soil parameters were averaged on an area weighted basis for subwatersheds that contained multiple soil types. Recommended Horton's equation parameters can be found in Table 3-5, below.

Table 3-5: Recommended Horton's equation parameters - Table 6-7 of USDCM (Reference 1)

NRCS Hydrologic Soil Group	Infiltration (inches per hour)		Decay Coefficient
	Initial	Final	
A	5	1	0.0007
B	4.5	0.6	0.0018
C	3	0.5	0.0018
D	3	0.5	0.0018

3.2 HYDROGRAPH ROUTING

Inflow hydrographs from each tributary along Sand Creek were placed at their confluence with Sand Creek for each design frequency. The inflow hydrographs were extracted from the outfall location SWMM models for each existing UDFCD study. As a method to calibrate the hydrologic model to the stream gage data, inflow hydrographs from each tributary was delayed. Toll Gate Creek was delayed four hours with all other watersheds delayed six hours. A comparison of peak discharges between existing studies and the conversion to CUHP v.2.0 can be found in Table 3-7 and Figure 3-5.

No new detention facilities were considered in the hydrologic analysis for the watersheds created as part of this study.

3.2.1 ROUGHNESS COEFFICIENT

Roughness coefficients (Manning's n) for pipes were increased by 25% to better represent modeling conditions per USDCM criteria when using EPA SWMM. No adjustments were made to the roughness coefficients in any of the existing study SWMM modeling.

3.2.2 CONVEYANCE ELEMENTS

Irregular trapezoidal channel elements with varying side slopes and base widths were used to represent Sand Creek. Outlet offsets were used to adjust the channel slope to better represent the conveyance channel slope, removing the elevation change associated with drop structures from each conduit. Elevation change from drop structures were estimated from project mapping.

A SWMM routing schematic can be found on the interactive map, located in Appendix B.

3.2.3 FLOW DIVERSIONS

The Denver Storm Drainage Master Plan identified a trans-basin flow diversion from B020 (Denver MP Basin 4400-02). Flow in excess of the pipe capacity (1,170 cfs) of the 108-inch RCP crossing the RTD track north, between Holly Street and Dahlia Street, is diverted west out of the Sand Creek Basin. This diversion has been represented in the SWMM model by a cutoff diversion element, diverting all flows in excess of 1,170 cfs out of the basin.

No diversion was analyzed at the Burlington Ditch as the irrigation canal was assumed full for all design storms.

3.3 CONVERSION OF PREVIOUS STUDIES

Each existing study was first executed using their original versions of CUHP and EPA SWMM. Basin parameters were then transferred to the CUHP v.2.0 worksheet. No calibration factors (Cp or Ct) used in prior studies were carried forward in the conversion process.

Varying rainfall point precipitation values and rainfall distributions were used in existing studies. Rainfall values were updated to the NOAA 14 point precipitation value selected for the Sand Creek Basin, further discussed in Section 3.2. Studies were then updated to use a 6-hr rainfall distribution for all subbasins. The depth reduction factor was revised in CUHP to reflect modeling of the entire Sand Creek Basin, approximately 180 square miles. The existing study EPA SWMM models were then executed using SWMM 5.1. Hydrographs were extracted at the outlet location for each design frequency for use as inflow hydrographs in the SWMM model downstream of Colfax Avenue.

As an example, a memo, detailing each step of the conversion process for Toll Gate Creek including intermediate hydrologic results, can be found in Appendix A.

3.4 PREVIOUS STUDIES

The effective Federal Emergency Management Agency (FEMA) Flood Insurance Study (FIS) hydrology for Sand Creek, downstream of Colfax Avenue, was originally established as part of the Sand Creek FHAD, dated March 1977. This study developed design flow rates for both existing and two future land conditions for the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year design storms. The two future land use scenarios projected basin populations of 600,000 people and 900,000 people with the floodplain delineation being based on the projected land use of 600,000 people. Rainfall values were obtained from the Weather Bureau and adjusted for depth-area and depth-duration relationship. Infiltration losses of 0.5 inch/hour were established from a comprehensive loss study for the Missouri River Basin.

The Sand Creek Colfax to Yale FHAD, prepared in 2012, established new hydrology for Sand Creek upstream of Colfax Avenue. This study, which used a six-hour rainfall distribution and previous versions of CUHP noted a reduction in discharge from FIS effective information.

A summary of effective discharges can be found in Table 3-11.

3.5 CALIBRATION OF HYDROLOGIC MODEL

During the initial development of the hydrologic models, a significant reduction in discharge was observed when compared to effective discharges. As another point of comparison, the FFA of the stream gage at the mouth of Sand Creek was reviewed. As mentioned in Section 2.1.3, Wright Water Engineers performed a flood frequency analysis for Sand Creek to support the 2016 South Platte River Hydrology CLOMR. The flood frequency analysis incorporated 19 years of record, from 1993-2013, to determine 95 percent confidence intervals of the estimated peak discharge. The analysis showed the 100-year flow estimate to be 20,080 cfs, with 95 percent confidence intervals spanning from 11,960 cfs to 48,090 cfs. The flood frequency analysis is the best available information of historic stream gage data and was used to help calibrate the hydrologic results. The flood frequency analysis can be found in Figure 3-3, below.

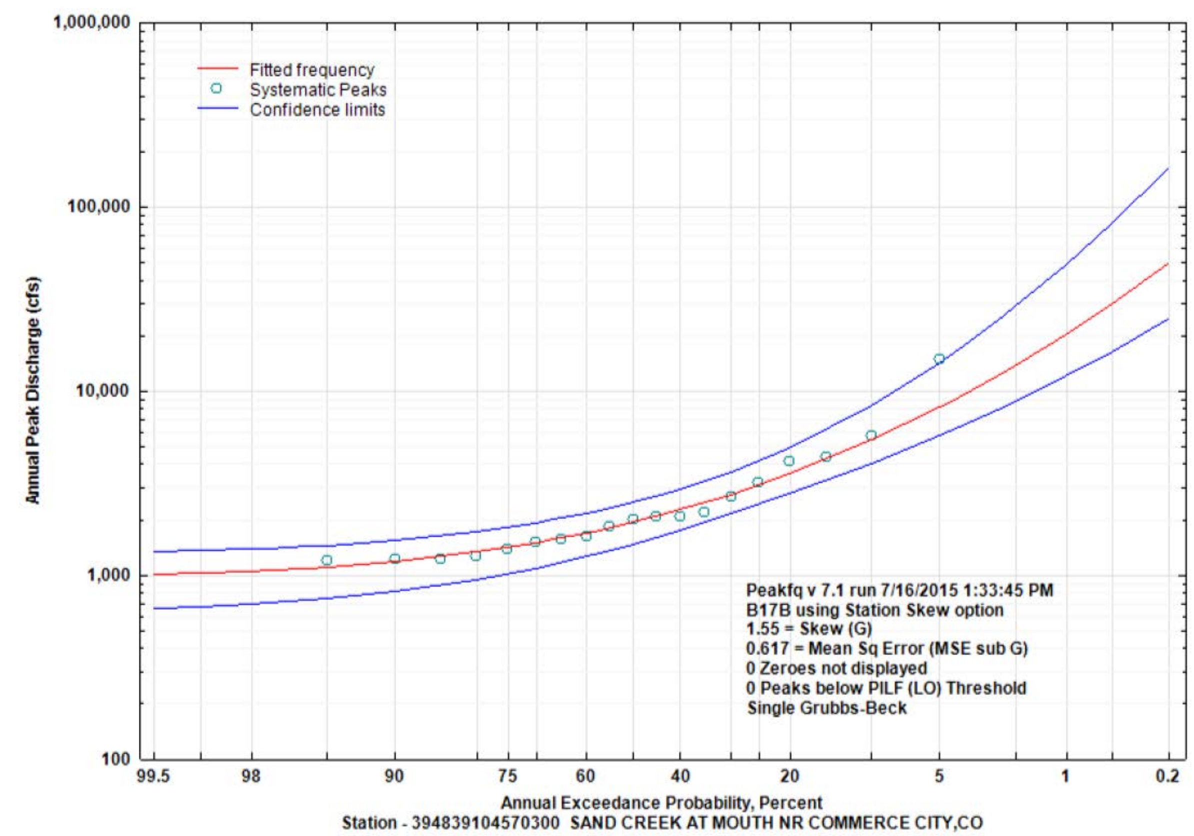


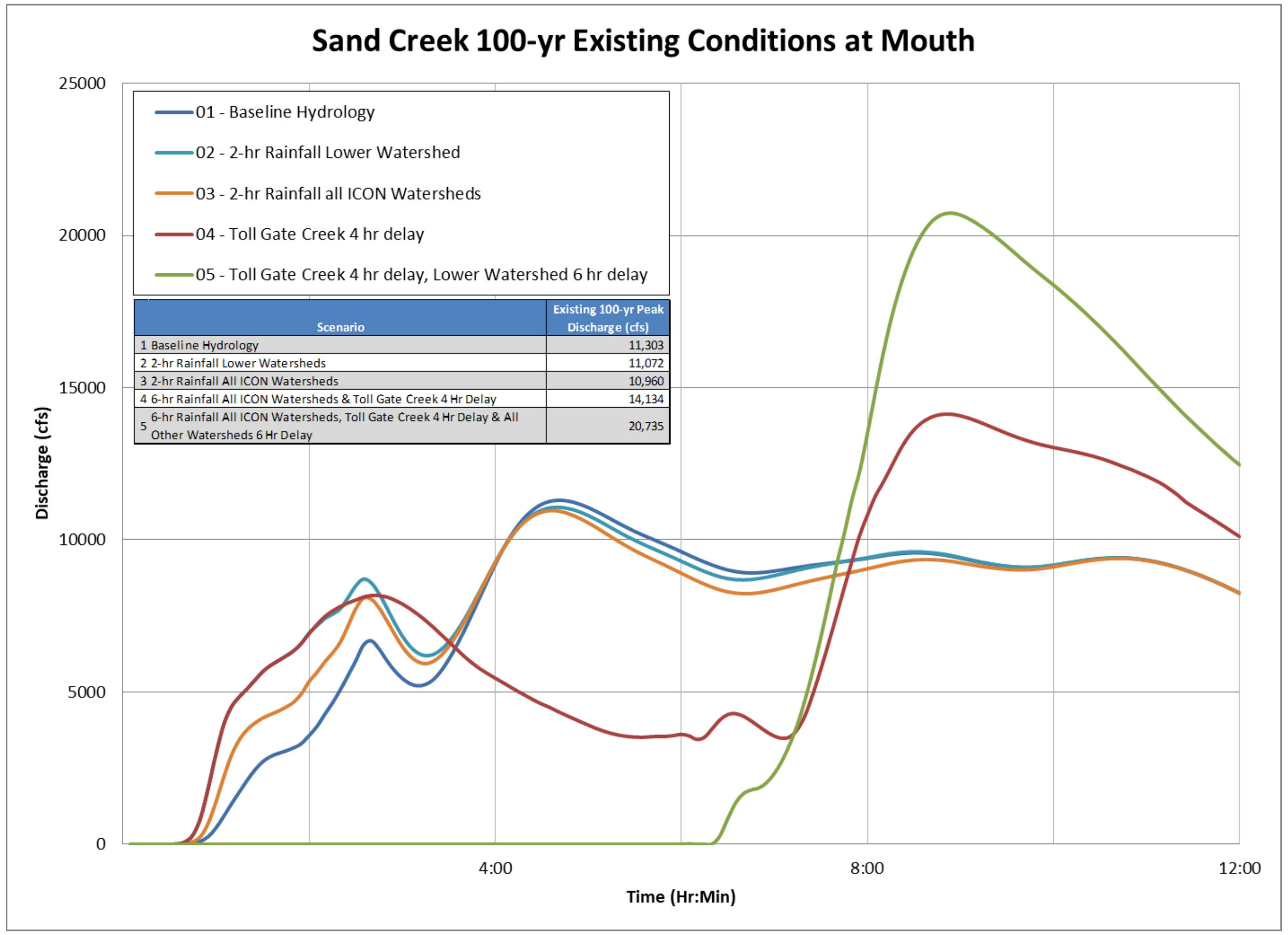
Figure 3-3: 2011 South Platte River CLOMR Bulletin 17 Analysis of Sand Creek (Reference 20)

The reduction in discharge originated from two distinct peaks, occurring first from Toll Gate Creek, followed by the peak along Sand Creek from the study upstream of Colfax Avenue. The double peaks observed in the in the baseline hydrology scenario can be observed by Scenario 1 in Figure 3-4.

To determine the best technique to calibrate the hydrologic model with the FFA analysis, several hydrologic scenarios were evaluated. The scenarios evaluated different approaches from varying the depth reduction factors within the lower watersheds and delays in the timing of tributary hydrographs to offset the peaking effects described above. The five scenarios that were evaluated are also depicted in Figure 3-4.

Scenario 1 reflects the baseline hydrology, existing conditions, model without calibration or adjustments. Scenario 2 modified the rainfall of the lower 10 square mile watersheds to reflect a 2-hour rainfall distribution along with a 6-hour distribution for the remainder of the watershed. Converse to calibration, the adjustment to a 2-hr rainfall distribution reduced the 100-year peak flow from 11,303-cfs to 11,072-cfs. Scenario 3 adjusted all of the watersheds delineated as part of this study (~16.8 sq. mi) to a 2-hour rainfall distribution. Similarly, this adjustment further reduced the 100-year peak flow to 10,960-cfs.

Scenarios 4 and 5 of the model calibration modified the timing of inflow hydrographs from tributaries to Sand Creek. First, for Scenario 4, the Toll Gate Creek hydrograph was delayed 4-hours to coincide with the upstream hydrograph from Sand Creek. This resulted in an increased peak discharge, of 14,134-cfs. Scenario 5 further delayed the lower watersheds 6-hours (in addition to the 4-hour delay on Toll Gate Creek) to coincide with the upstream hydrograph timing. This scenario resulted in an increase in the 100-year discharge at the mouth of Sand Creek of 20,735-cfs, correlating well with the to the FFA stream gage estimated 100-year existing condition discharge of 20,080-cfs. The proportion of delay in response from the lower tributaries is supported by the individual watershed size in relation to the Sand Creek Basin and affects anticipated from urbanization. With the lower watersheds being smaller in size, with a much faster response time, the increased delay would be needed to reflect an appropriate hydrograph response time for the urbanized basin and to maximize runoff potential.



	Scenario	Existing 100-yr Peak Discharge (cfs)
1	Baseline Hydrology	11,303
2	2-hr Rainfall Lower Watersheds	11,072
3	2-hr Rainfall All ICON Watersheds	10,960
4	6-hr Rainfall All ICON Watersheds & Toll Gate Creek 4 Hr Delay	14,134
5	6-hr Rainfall All ICON Watersheds, Toll Gate Creek 4 Hr Delay & All Other Watersheds 6 Hr Delay	20,735

Figure 3-4: Hydrology Scenario Comparison

3.6 RESULTS OF ANALYSIS

A comparison of peak discharges between existing studies and the conversion to CUHP v.2.0 can be found in Table 3-9. A summary of peak flows at design points throughout the basin can be found in Table 3-10. Peak discharge and inflow volumes for each design point during all design storm frequencies for both existing and future land use conditions can be found in Appendix B.

Even with the calibration of delaying the inflow hydrographs, it should be noted that the 100-year discharges are approximately 30% lower than effective discharges in the lower reaches of the study. The effective discharge from the 1977 FHAD was developed using future population land use projections, whereas, the current study calibrated existing conditions land use to the stream gage FFA before applying future land use projections. Future conditions discharges compare similarly to effective discharges downstream of Toll Gate Creek.

With existing and future land use 100-year discharges varying in excess of thirty percent, the existing conditions discharge will be used for developing flood hazard information for future Flood Insurance Rate Map (FIRM) revisions. The future conditions land use 100-year discharges will be used to develop the FHAD.

3.7 VALIDATION OF HYDROLOGIC RESULTS & MODEL CALIBRATION

Numerous steps were taken to validate the hydrologic results, given the introduction of a rainfall-runoff model on an approximately 180 square mile watershed, and the methods of calibration used to align with the stream gage FFA results. Validation steps included preparing a comparison using a variety of hydrologic models at Colfax Avenue and the mouth of Sand Creek, and the completion of an independent review by Dr. James Guo, an author of CUHP.

3.7.1 CUHP VALIDATION

To validate the use of CUHP v.2.0 of an approximately 180 square mile watershed, UDFCD independently completed a comparison analysis for Sand Creek at Colfax Avenue. This location was chosen as a reference point from the upper watershed study which was recently completed and had a complete, approved model available. The following items were used for the comparison:

1. Compare CUHP Version 1.3.1 to Version 2.0.0.
2. Estimate Peak Flows at a USGS Gage on Sand Creek using Bulletin 17B methods.
3. Estimate Peak Flows for the Foothill Regions under USGS Stream Stats.
4. Develop a Historic CUHP Version 2.0.0 Model to Compare to (3) above.

The results of this comparison are summarized in Table 3-6, below. At Colfax Avenue, CUHP v.2.0 produces a similar historic discharge to USGS Stream Stats analysis at the same location. The unit discharge of both CUHP v.2.0 and the Stream Stats analysis at Colfax Avenue compare favorably to the unit discharge at the mouth of Sand Creek from the FFA. Based on this analysis, it was determined that use of CUHP 2.0.0 would be an appropriate rainfall-runoff model for this size of this hydrologic study. The findings of the memo can be found below, with the entirety of the memo found in Appendix A.

Table 3-6: Comparison of Model Discharges along Sand Creek at Colfax Avenue

Method	Area (sq mi)	Land Use Scenario	100-yr Peak Flow (cfs)	Unit Discharge (cfs / sq mi)
CUHP 1.3.1 and SWMM 5 (Matrix, 2013)	92	Future	19,245	210
CUHP 2.0.0 and SWMM 5	92	Future	15,000	164
Bulletin 17B (WWE, 2011)[1]	187	Existing	20,000	107
USGS Stream Stats - Sand Creek at Colfax	105	Existing	8,450	80
CUHP 2.0.0 and SWMM 5[2]	92	Existing	8,733	95

1 - Sand Creek at Mouth (USGS)
2 - Historic 2% Imp - This is to compare with Foothills Region Stream Stats above

3.7.2 INDEPENDENT REVIEW OF MODELING APPROACH

An independent review of the hydrology recommendations was completed by Dr. James Guo, an author of CUHP, to review the modeling approach and sub-basin parameters applied to the hydrologic analysis of the Sand Creek watershed. The City of Denver and UDFCD met with Dr. Guo on February 8, 2018, to discuss the results of his review. Dr. Guo confirmed that CUHP was appropriate to model a larger watershed, including Sand Creek. The Sponsors discussed the information available at the USGS Gage along Sand Creek near the confluence with the South Platte River. Dr. Guo agreed that this information was valuable data that could be used to confirm modeling assumptions and calibrate the hydrologic model. The model calibration process requires consideration of which modeling parameters are most appropriate to adjust to achieve desired results without compromising what is physically possible. Dr. Guo confirmed the modeling parameters the project team selected, such as the Depth Reduction Factor, depression loss, and infiltration coefficients. Dr. Guo noted that with urbanization reach parameters (hydrograph routing) become extended due to the more complex storm sewer systems and street flow that inherently occurs and the increase in roughness values through the urban systems. As such, the timing of the inflow basin hydrographs was recommended as a calibration procedure given that each tributary model does not extend hydrograph routing to fully account for the effects of urbanization within each basin.

Table 3-7: Changes to Existing Studies

Figure 3-1 ID	Tributary Name	Study Name	Watershed Area (sq. mi)	Effective CUHP version	Conversion Process for Existing Studies: Convert to CUHP v.2.0 (Remove Calibration Factors)	NOAA 14 Rainfall to 6-hr Distribution	DRF for Sand Creek Basin	Convert SWMM to version 5.1
1	Murphy Creek	Murphy Creek FHAD (2006)	12.63	1.2.1	Yes	Yes	Yes	Yes
2	Sand Creek - Colfax to Yale	Sand Creek Colfax to Yale MDP (2013)	91.97	1.3.3	Yes	Yes	Yes	Yes
3	Sand Creek Right Bank (1101)	Sand Creek Right Bank OSP (2016)	7.96	1.4.3	Yes	Yes	Yes	Yes
4	Sand Creek Right Bank (901)	Sand Creek Right Bank OSP (2016)	7.96	1.4.3	Yes	Yes	Yes	Yes
5	Upper Toll Gate Creek	East Toll Gate (Upper) FHAD (2010)	2.43	1.3.1	Yes	Yes	Yes	Yes
6	West Toll Gate Creek	West Toll Gate Creek FHAD (2013)	23.59	1.3.3	Yes	Yes	Yes	Yes
7	Toll Gate Creek	Toll Gate Creek & East Toll Gate Creek MDP (2014)[1]	16.26	1.3.3	Yes	Yes	Yes	Yes
8	Baranmoor Ditch	Baranmor Ditch Watershed OSP (2010)	1.75	1.3.3	Yes	Yes	Yes	Yes
9	Westerly Creek	Westerly Creek Lower FHAD Hydrology (2017)	17.44	1.4.4	N/A	N/A	Yes	N/A

1 - Infiltration values were adjusted to better match UDFCD recommended values

Table 3-8: Existing Studies 100-year Existing Discharge Comparison

Figure 3-5 ID	Tributary Name	Study Name	Watershed Area (sq. mi)	Effective CUHP version	Time to Peak Flow (Hr:Min)		100-year Future Conditions Peak Discharge (cfs)		
					Original	CUHP v.2.0	Original	CUHP v.2.0	Reduction (%)
1	Murphy Creek	Murphy Creek FHAD (2006)	12.63	1.2.1	1:20	3:05	2,834	2,097	-26%
2	Sand Creek - Colfax to Yale	Sand Creek Colfax to Yale MDP (2013)	91.97	1.3.3	6:35	7:35	13,368	8,133	-39%
3	Sand Creek Right Bank (1101)	Sand Creek Right Bank OSP (2016)	7.96	1.4.3	0:40	0:55	707	255	-64%
4	Sand Creek Right Bank (901)	Sand Creek Right Bank OSP (2016)	7.96	1.4.3	1:00	1:30	427	170	-60%
5	Upper Toll Gate Creek	East Toll Gate (Upper) FHAD (2010)	2.43	1.3.1	2:09	2:40	906	548	-40%
6	West Toll Gate Creek	West Toll Gate Creek FHAD (2013)	23.59	1.3.3	1:26	1:40	15,027	8,934	-41%
7	Toll Gate Creek	Toll Gate Creek & East Toll Gate Creek MDP (2014)	16.26	1.3.3	1:55	2:10	22,588	10,187	-55%
8	Baranmoor Ditch	Baranmor Ditch Watershed OSP (2010)	1.75	1.3.3	1:15	1:40	1,325	606	-54%
9	Westerly Creek	Westerly Creek Lower FHAD Hydrology (2017)	17.44	1.4.4	1:35	1:25	4,424	3,290	-26%

Table 3-9: Existing Studies 100-year Future Discharge Comparison

Figure 3-6 ID	Tributary Name	Study Name	Watershed Area (sq. mi)	Effective CUHP version	Time to Peak Flow (Hr:Min)		100-year Future Conditions Peak Discharge (cfs)		
					Original	CUHP v.2.0	Original	CUHP v.2.0	Reduction (%)
1	Murphy Creek	Murphy Creek FHAD (2006)	12.63	1.2.1	1:05	1:50	3,614	2,606	-28%
2	Sand Creek - Colfax to Yale	Sand Creek Colfax to Yale MDP (2013)	91.97	1.3.3	4:20	4:50	19,246	13,585	-29%
3	Sand Creek Right Bank (1101)	Sand Creek Right Bank OSP (2016)	7.96	1.4.3	0:40	0:55	1,494	547	-63%
4	Sand Creek Right Bank (901)	Sand Creek Right Bank OSP (2016)	7.96	1.4.3	0:50	1:15	464	186	-60%
5	Upper Toll Gate Creek	East Toll Gate (Upper) FHAD (2010)	2.43	1.3.1	1:06	2:35	1,048	623	-41%
6	West Toll Gate Creek	West Toll Gate Creek FHAD (2013)	23.59	1.3.3	1:27	1:40	15,558	9,334	-40%
7	Toll Gate Creek	Toll Gate Creek & East Toll Gate Creek MDP (2014)	16.26	1.3.3	1:55	2:05	23,005	13,551	-41%
8	Baranmoor Ditch	Baranmor Ditch Watershed OSP (2010)	1.75	1.3.3	1:09	1:30	1,811	893	-51%
9	Westerly Creek	Westerly Creek Lower FHAD Hydrology (2017)	17.44	1.4.4	1:40	1:25	4,742	3,290	-31%

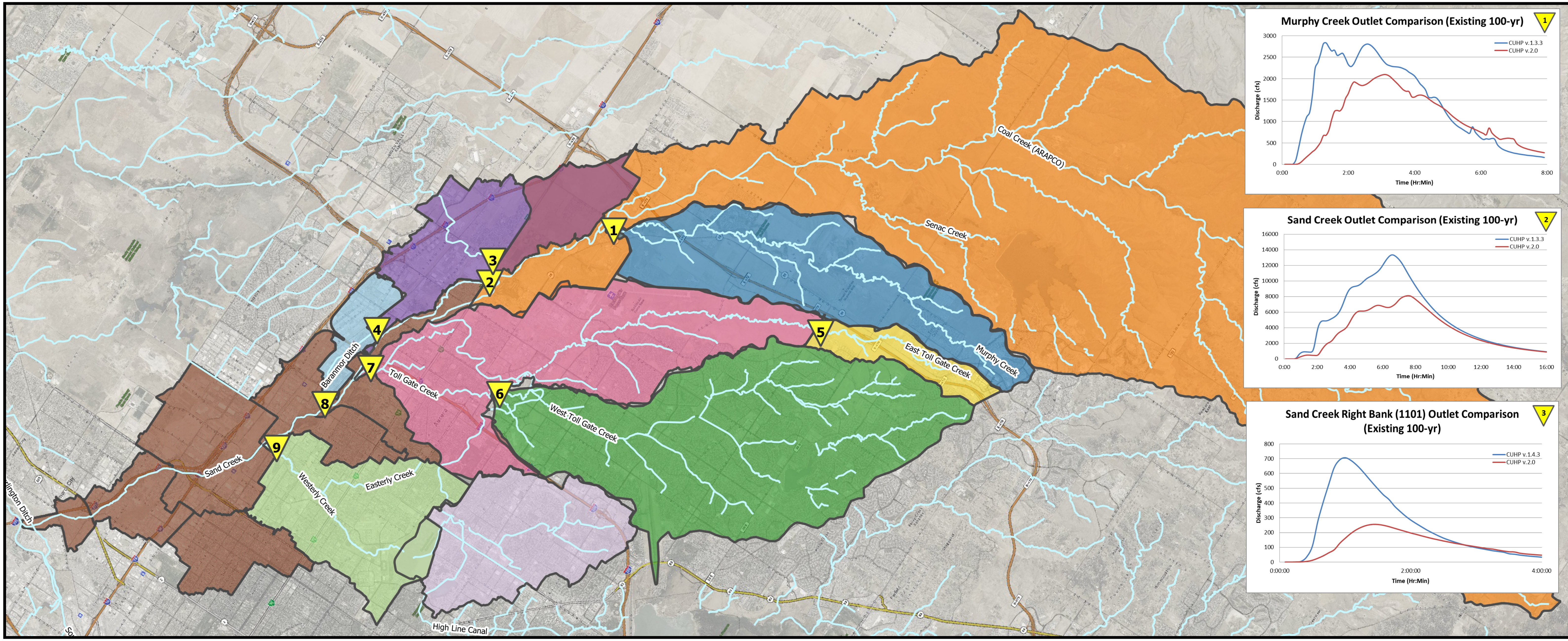
Table 3-10: Hydrology Results

Figure 3-7 ID	Location	SWMM Design Point	Existing Land Use (cfs)							Future Land Use (cfs)						
			2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	500-yr	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	500-yr
10	Colfax Avenue	J140	506	739	1,012	2,607	4,140	8,415	18,488	1,588	2,363	3,218	6,800	9,754	13,582	24,194
9	Chambers Road	J100	614	920	1,289	2,856	4,686	9,089	19,200	1,846	2,732	3,695	7,185	9,721	13,570	24,255
8	Confluence with Toll Gate Creek	J070	1,184	1,746	2,436	7,165	10,933	16,525	33,714	2,987	4,342	5,887	13,723	19,604	26,858	43,209
7	Peoria Street	J060	1,213	1,790	2,512	7,100	10,727	16,332	33,159	3,074	4,483	6,098	13,721	19,490	26,675	43,103
6	Confluence with Baranmor Ditch	J050	1,305	1,943	2,783	7,440	10,904	16,375	33,025	3,269	4,791	6,567	14,211	19,554	26,625	43,064
5	Confluence with Westerly Creek	J040	1,562	2,321	3,386	8,983	12,979	19,510	39,148	3,646	5,291	7,185	15,924	21,663	28,040	46,236
4	Quebec Street	J030	1,690	2,497	3,609	9,119	13,319	20,100	41,450	3,845	5,550	7,506	16,600	22,817	30,600	50,638
3	Vasquez Boulevard	J020	1,833	2,666	3,810	9,499	13,783	20,671	42,928	4,064	5,828	7,844	17,031	23,557	31,662	52,864
2	Brighton Boulevard	J010	1,855	2,696	3,844	9,562	13,861	20,764	43,138	4,106	5,880	7,903	17,131	23,697	31,876	53,278
1	Mouth	Outfall	1,855	2,695	3,843	9,557	13,844	20,740	43,104	4,105	5,879	7,901	17,115	23,671	31,835	53,267

Table 3-11: Hydrology Reconciliation

Figure 3-7 ID	Location	SWMM Design Point	100-year Discharge (cfs)				
			1977 FHAD[1]	MDP Existing	Difference (%)	MDP Future	Difference (%)
10	Colfax Avenue	J140	19,312[2]	8,415	-56%	13,582	-30%
9	Chambers Road	J100	21,500	9,089	-58%	13,570	-37%
8	Confluence with Toll Gate Creek	J070	21,500	16,525	-23%	26,858	25%
7	Peoria Street	J060	29,200	16,332	-44%	26,675	-9%
6	Confluence with Baranmor Ditch	J050	29,200	16,375	-44%	26,625	-9%
5	Confluence with Westerly Creek	J040	29,200	19,510	-33%	28,040	-4%
4	Quebec Street	J030	30,000	20,100	-33%	30,600	2%
3	Vasquez Boulevard	J020	30,500	20,671	-32%	31,662	4%
2	Brighton Boulevard	J010	30,500	20,764	-32%	31,876	5%
1	Mouth	Outfall	30,500	20,740	-32%	31,835	4%

1 - 1977 FHAD Discharges were developed for future land use projection
2 - Discharge from Sand Creek Colfax to Yale 2012 FHAD



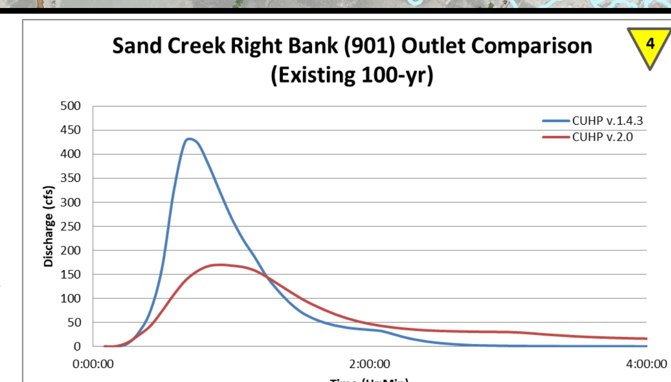
Sand Creek Major Drainageway Plan

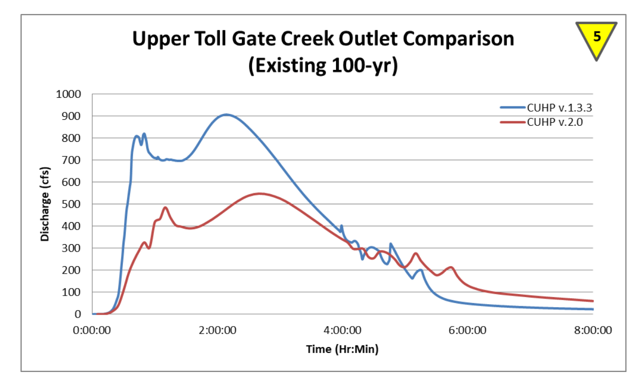
Figure 3-5: Existing Studies
100-Year Existing Discharge Comparison

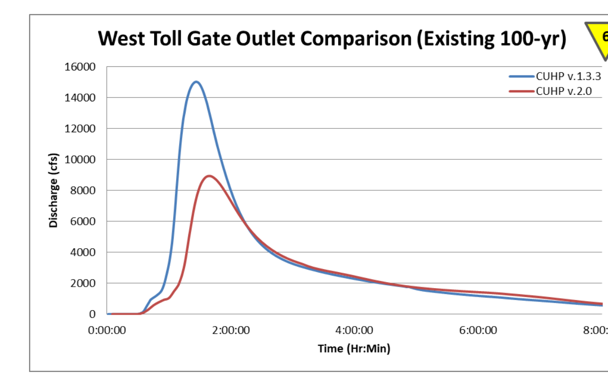
North

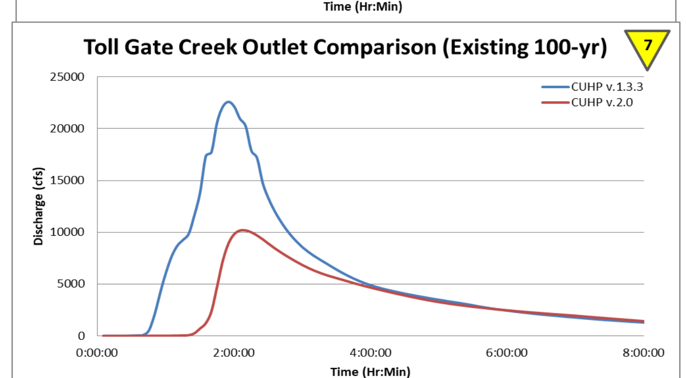
0 1 2 3 mi

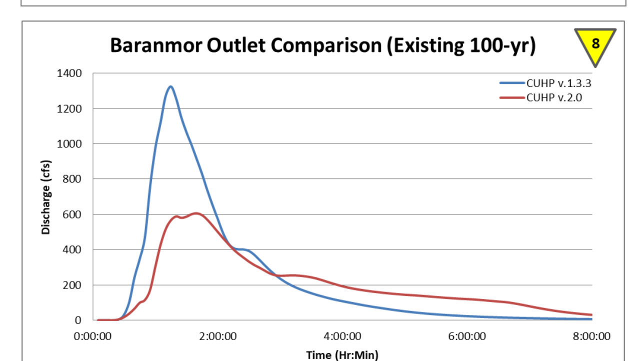
- Baranmoor (2010)
- Sand Creek Right Bank Trib (2016)
- Sand Creek - Colfax to Yale (2013)
- Toll Gate Creek East (2014)
- Toll Gate Creek East Upper (2010)
- Toll Gate Creek West (2013)
- Westerly Creek Lower (2016)
- Westerly Creek Upper (2015)
- Murphy Creek (2006)
- Sand Creek Subwatersheds
- UDFCD Streams
- Sand Creek Study Outfalls

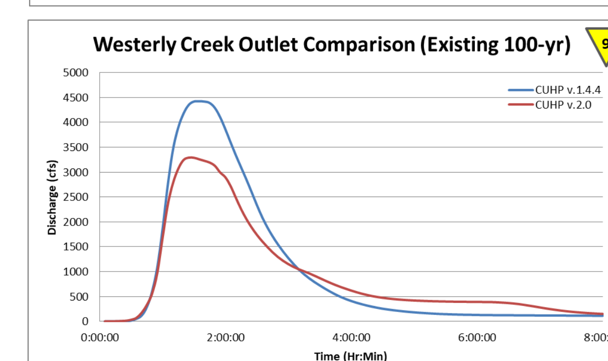


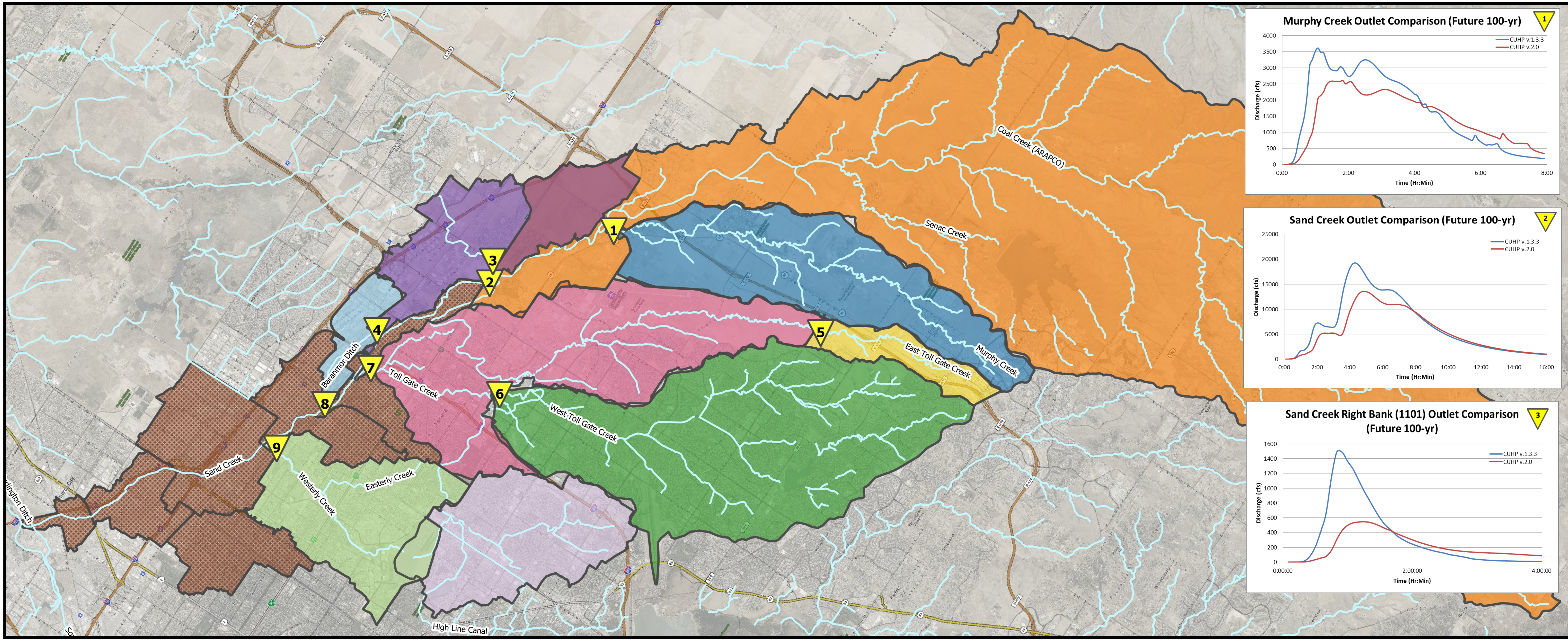












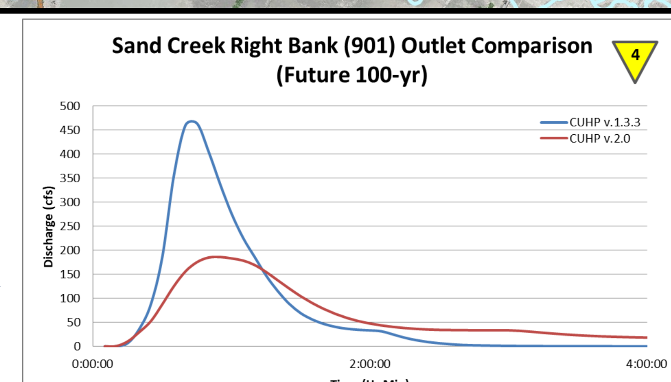
Sand Creek Major Drainageway Plan

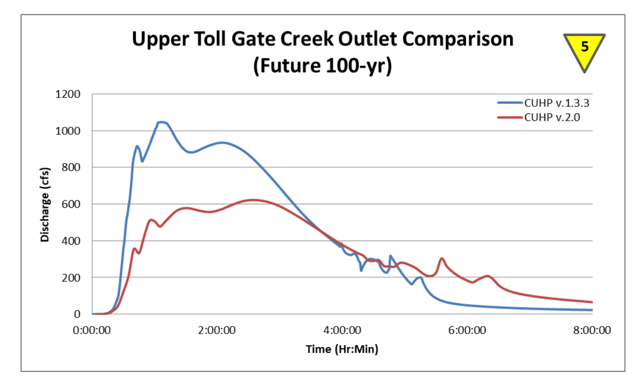
Figure 3-6: Existing Studies
100-Year Future Discharge Comparison

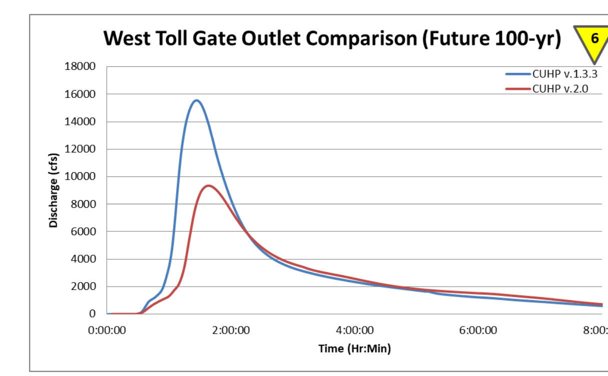
North

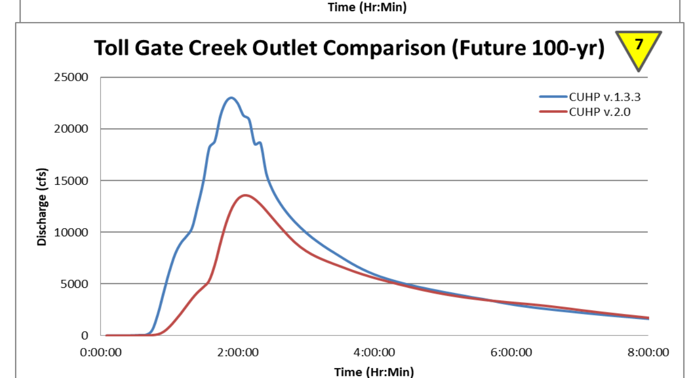
0 1 2 3 mi

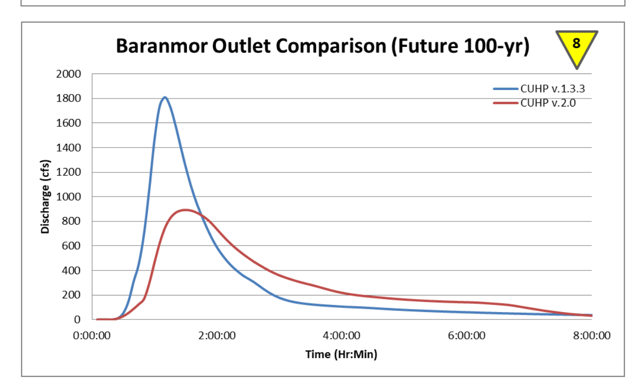
Baranmoor (2010)	Westerly Creek Lower (2016)
Sand Creek Right Bank Trib (2016)	Westerly Creek Upper (2015)
Sand Creek - Colfax to Yale (2013)	Murphy Creek (2006)
Toll Gate Creek East (2014)	Sand Creek Subwatersheds
Toll Gate Creek East Upper (2010)	UDFCD Streams
Toll Gate Creek West (2013)	Sand Creek Study Outfalls

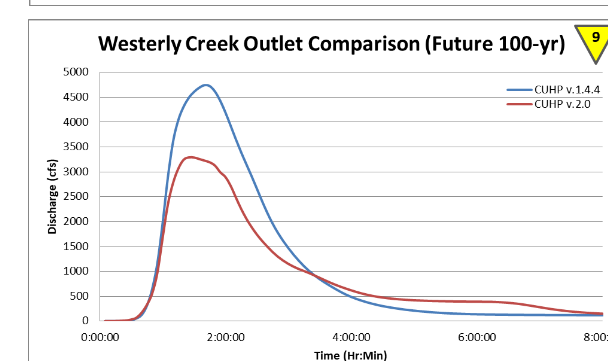


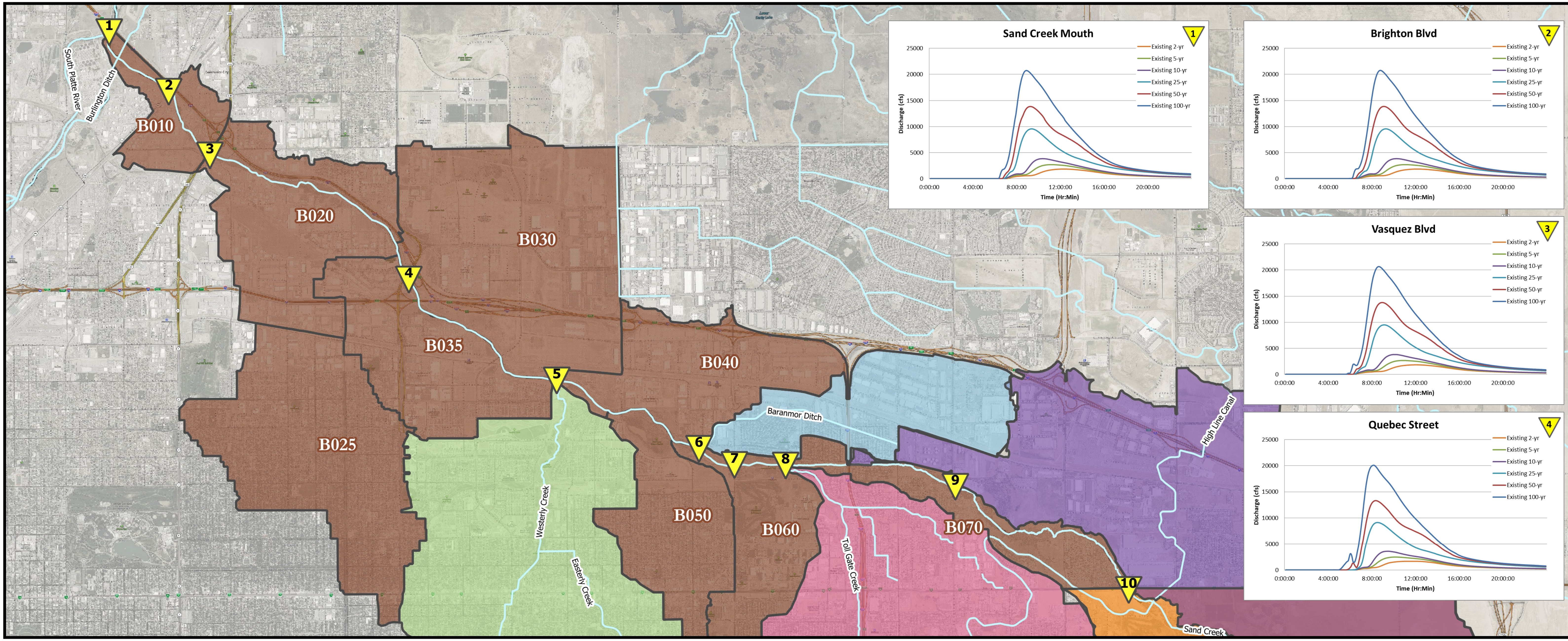












Sand Creek Major Drainageway Plan

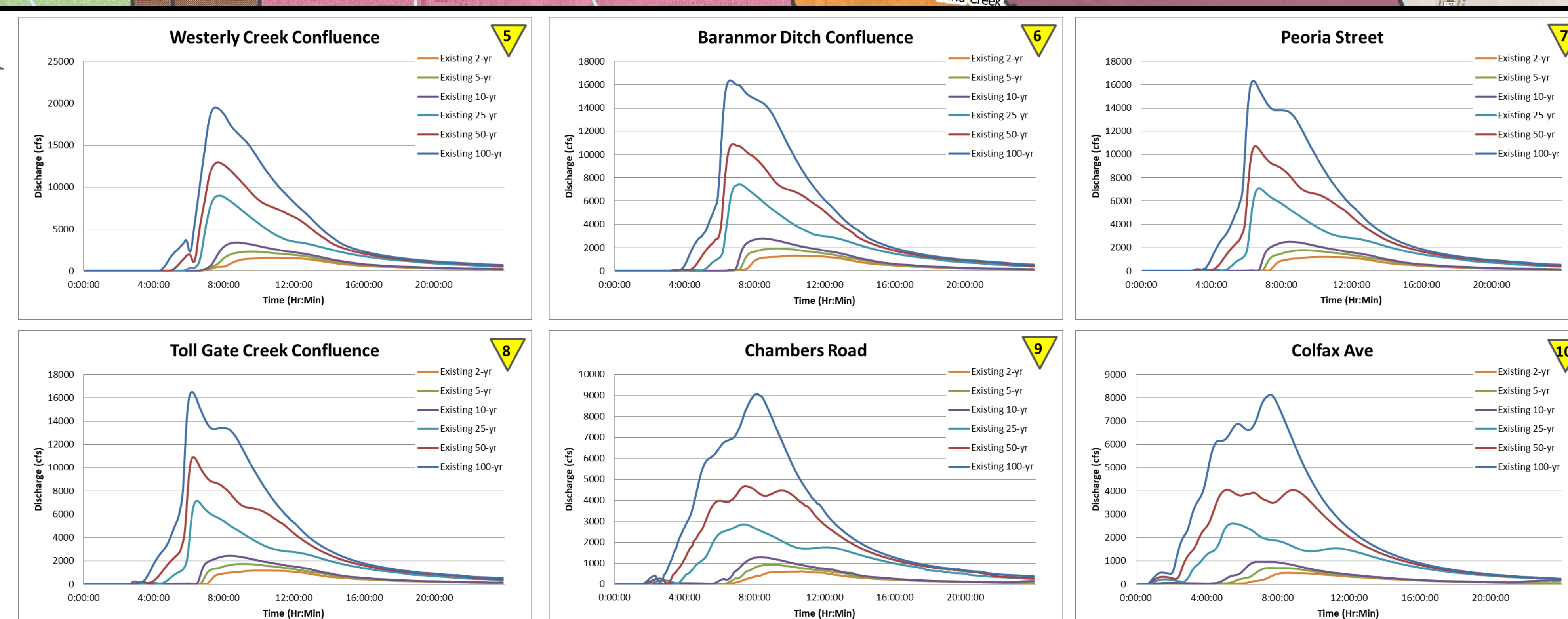
Figure 3-7: Existing Conditions Hydrology Results

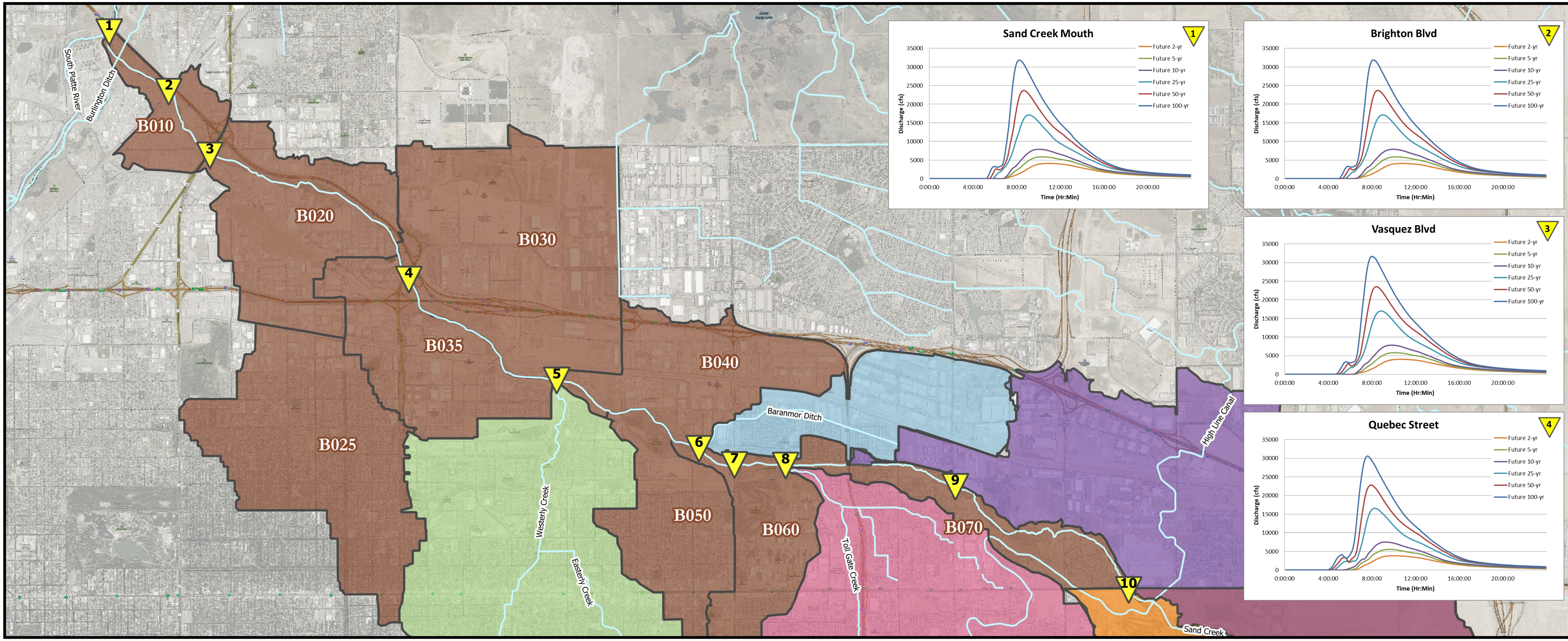
North

ICON ENGINEERING, INC. Commerce CITY AURORA DENVER THE MILE HIGH CITY

0 1 mi

- Baranmoor (2010)
- Sand Creek Right Bank Trib (2016)
- Sand Creek - Colfax to Yale (2013)
- Toll Gate Creek East (2014)
- Toll Gate Creek East Upper (2010)
- Toll Gate Creek West (2013)
- Westerly Creek Lower (2016)
- Westerly Creek Upper (2015)
- Murphy Creek (2006)
- Sand Creek Subwatersheds
- UDFCD Streams
- Sand Creek Study Outfalls





Sand Creek Major Drainageway Plan

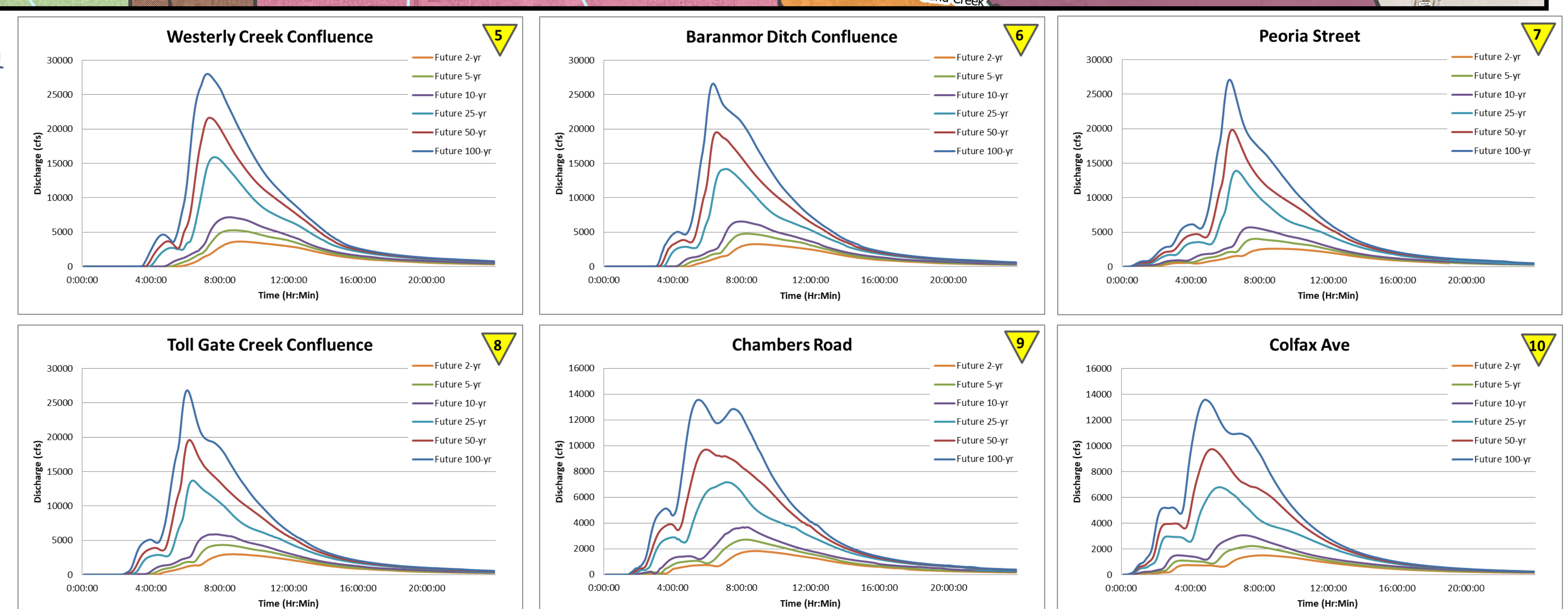
Figure 3-8: Future Conditions Hydrology Results

North

ICON ENGINEERING, INC.
Commerce CITY
AURORA
DENVER THE MILE HIGH CITY

0 1 mi

Baranmoor (2010)	Westerly Creek Lower (2016)
Sand Creek Right Bank Trib (2016)	Westerly Creek Upper (2015)
Sand Creek - Colfax to Yale (2013)	Murphy Creek (2006)
Toll Gate Creek East (2014)	Sand Creek Subwatersheds
Toll Gate Creek East Upper (2010)	UDFCD Streams
Toll Gate Creek West (2013)	Sand Creek Study Outfalls



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16. J3 Engineering Consultants (2013) Toll Gate Creek and East Toll Gate Creek (Downstream of Hampden) Flood Hazard Delineation
17. Michael Baker Jr., Inc., Enginuity Engineering Solutions (2013) Flood Hazard Area Delineation, West Toll Gate Creek
18. CH2M Hill (2015) Westerly Creek (Upstream of the Westerly Creek Dam Outlet) Major Drainageway Plan
19. UDFCD (2017) Memorandum: Sand Creek Gage Information and CUHP Validation
20. Wright Water Engineers, Inc. (2016) CLOMR Request for South Platte River, Chatfield to Fort Lupton

APPENDIX A - PROJECT CORRESPONDENCE

Sand Creek MDP & FHAD
Kick-off Meeting
August 22, 2017 2:30 PM

UDFCD Offices
Meeting Minutes

Attendees:	*Curtis Bish,*	*City of Aurora – PROS*
	Bill McCormick,	*City of Aurora – Public Works*
	Craig Perl,	*City of Aurora – Public Works*
	Sarah Young,	*City of Aurora – Water*
	Jon Villines,	*City of Aurora – Water*
	Andrew Pihaly,	*City of Commerce City*
	Bruce Uhernik,	*City of Denver – Public Works*
	Cincere Eades (by phone),	*City of Denver – Parks and Rec*
	Jeremy Hamer,	*City of Denver – Floodplain*
	David Morrisey,	*City of Denver – Floodplain*
	Morgan Lynch,	*Urban Drainage and Flood Control District*
	Shea Thomas,	*Urban Drainage and Flood Control District*
	Craig Jacobson,	*ICON Engineering*
	Jaclyn Michaelsen,	*ICON Engineering*
	Jeremy Deischer,	*ICON Engineering*

Anticipated Schedule

- Morgan and Shea provided an overview on the new approach UDFCD is taking on MDP / FHAD studies. After the hydrology is complete the team will proceed into the FHAD portion of the study. This new approach will allow the team to develop an existing conditions floodplain before developing alternatives. After the FHAD is complete the team will continue with developing alternatives and the conceptual design portion of the study. Colfax Avenue, the upstream limit of the study, was identified as a key concern and may be analyzed for alternatives before the FHAD portion is complete.
- Jeremy Hamer asked about the role of the stakeholders during the FHAD process. Morgan and Shea will provide stakeholders the opportunity to provide any comments within each review period for the FHAD.
- Craig Jacobson indicted the hydrology portion of the study is expected to be completed sooner than the allotted 16 weeks.
- After some discussion, the team decided to hold a public meeting near the end of the FHAD portion of the study. This would allow the floodplain delineation to be completed and be able to properly identify risks and gather input from the public before developing the alternatives.
- Shea described the approach to the conceptual design of the study. The intent is not to produce an exact preliminary design for the proposed improvements but rather provide the intent of the improvements. The design of the proposed improvements will be refined to a level such that an accurate cost estimate can be provided. Craig Jacobson noted this approach was very similar to the Boulder Creek Restoration Master Plan that ICON completed in 2015. ICON will be using the same subconsultant for the geomorphic assessment that was used for Boulder Creek, Ecological Resource Consultants, Inc.

Table Discussion – Key Components of Study to Stakeholders

- The discussion of specific areas of interest to each stakeholder was tabled until later in the project. Instead the team discussed what each stakeholder wanted to get out of this study.
  - City of Aurora:
    - Improve the ecological function of the stream corridor
    - Evaluate the possible aggradation of the soil cement channel
    - Evaluate roadway crossings at Colfax Avenue, Alameda Avenue, and Chambers Road.
    - Evaluate the Zone X with reduced flood risk due to levee near Chambers Road.
    - Evaluate possible spill of Sable Ditch into Sand Creek
  - City of Denver:
    - Reduction in flood risk
    - Create a stable channel that seamlessly integrates with open space and parks to create more of an amenity than strictly a conveyance system.
    - The Stapleton redevelopment area. Jeremy Hamer described the development currently in the area which included moving the existing detention basin to the west across Central Park Boulevard.
  - City of Commerce City:
    - Reduction in flood risk
    - Andrew informed the team of the redesign of the I-270 and Vasquez Boulevard intersection. The ramp of I-270 to I-70 is also in redesign.
  - UDFCD
    - Morgan described the district's interest in the updated floodplain delineation and trying to improve Sand Creek as it is currently on the State of Colorado's 303D, impaired waters, list.
- Curtis asked about if any environmental investigation would be done as part of this study. Craig Jacobson stated this study would focus on stream health and the geomorphology of the stream but not site specific environmental assessments.

Hydrology Scope and Approach

- Craig Jacobson overviewed the approach to updating the hydrology for Sand Creek. Existing hydrology models for UDFCD master plans will be used to generate inflow hydrographs for each tributary along Sand Creek. Existing studies will be updated to CUHP version 2.0 and NOAA Atlas 14 rainfall. Additional subwatersheds will be created for areas that are not accounted for in existing UDFCD studies. It was anticipated that around 5 additional subwatersheds would be needed. These areas would be large scale, not delineated down to 130-acre subwatersheds.
- The City of Aurora informed the team that a hydrology study had been completed for the Peoria Street Basin. The City anticipated a project for construction in 2019 that would convey 100-year flows from the Peoria Street Basin into Sand Creek.
- The City of Aurora also has a hydrology study currently ongoing for Old Aurora. It is not anticipated this study would be complete in time for use for this study.
- Jeremy Hamer asked whether the hydrology model would be calibrated to the gage data. Morgan described how the stream gage data is not accurate enough to calibrate a model given the years of record and ditch influences. The team briefly questioned how the South Platte River Hydrology CLOMR incorporated the Sand Creek gage data. The team will look into the Wright Water Engineers report on the South Platte River hydrology and how the gage data was used.

- The team discussed the data to be used for the existing conditions imperviousness. The City of Denver and Aurora had existing conditions imperviousness layers they could provide. Commerce City was unsure if this information was available. Shea described the National Land Cover Dataset with slight modifications was also acceptable to determine existing conditions land use.

Website & Communication

- Each stakeholder identified which contact should be listed on the project website.
- The City of Aurora has a new logo they will provide to be used on the website.
- A comment form section will be added to the website to allow the public to easily submit comments on the study.
- The website can be further reviewed at the following link: http://www.iconeng.com/project/sand-creek/

The next meeting will present the results of the hydrologic analysis before submitting to the hydrology models to stakeholders for review. This meeting will be set up in approximately three (3) to four (4) weeks.

Action Items:

City of Aurora will provide:

- Updated logo for project website
- Peoria Street Basin Hydrology Report
- Existing conditions impervious GIS shapefile

City of Denver will provide:

- Existing conditions impervious GIS shapefile

Commerce City will provide:

- Zoning GIS shapefile (if available)
- Existing conditions impervious GIS shapefile (if available)

- END OF MEETING--

To the best of my knowledge, these minutes are a factual account of the business conducted, the discussions that took place, and the decisions that were reached at the subject meeting. Please direct any exceptions to these minutes in writing to the undersigned within ten (10) days of the issue date appearing herein. Failure to do so will constitute acceptance of these minutes as statements of fact in which you concur.

Minutes prepared by: Jeremy Deischer

Jeremy Deischer, EI — August 25, 2017
ICON Engineering, Inc.

Sand Creek MDP & FHAD
Hydrology Progress Meeting
October 30, 2017 2:00 PM

UDFCD Offices
Meeting Minutes

Attendees:		
	Curtis Bish,	*City of Aurora – PROS*
	Craig Perl,	*City of Aurora – Public Works*
	Katie Thompson,	*City of Aurora*
	Jon Villines,	*City of Aurora – Water*
	Andrew Pihaly,	*City of Commerce City*
	Cincere Eades,	*City of Denver – Parks and Rec*
	Jeremy Hamer,	*City of Denver – Floodplain*
	David Morrisey,	*City of Denver – Floodplain*
	Sam Pavone,	*City of Denver – Wastewater CPM*
	Morgan Lynch,	*Urban Drainage and Flood Control District*
	Shea Thomas,	*Urban Drainage and Flood Control District*
	Craig Jacobson,	*ICON Engineering*
	Jaclyn Michaelsen,	*ICON Engineering*
	Jeremy Deischer,	*ICON Engineering*

Baseline Hydrology Report Overview

ICON provided an overview of the DRAFT Baseline Hydrology Report that was submitted to stakeholders October 24th. Each aspect of the hydrology was discussed in further detail.

Subwatershed Delineation:

- Jon Villines noted the existing Original Aurora and Peoria Street Outfall studies that the City provided. The basin delineations for the Original Aurora and Westerly Creek FHAD studies significantly overlapped. The Original Aurora subwatersheds were summarized into one subbasin to account for the area not included in the Westerly Creek FHAD. The basin delineations for the Peoria Street Outfall only accounted for basins directly tributary to this outfall. These subwatersheds were summarized into one subbasin for the Sand Creek study.

Rainfall:

- David Morrisey suggested examining the isopluvial maps in NOAA 14 to see how rainfall spatially varied throughout the basin. The team discussed how using spatially varied rainfall data and different temporal distributions for each subwatershed might impact the response time of each watershed and concluded that other rainfall distribution combinations should be checked to determine a realistic worst case for 100-year flood peaks. The response time of each watershed was a key point of discussion given the two distinct peaks produced by the hydrologic analysis and based on the 181 square mile watershed area being 35 miles long by 8 miles wide.

Existing Imperviousness:

- The City of Aurora and the City of Denver indicated they prefer using the existing impervious layers for subwatersheds in their jurisdictions, pointing out that impervious values for single family in Table 2.1 may be too low based on current zoning trends. ICON will revise the existing impervious values to reflect each jurisdictions impervious values.

Future Imperviousness:

- The City of Denver commented that the future impervious values used in this study were lower than the general values in the City of Denver Stormwater Master Plan. ICON will review the City of Denver Stormwater Master Plan to see what land use assumptions were used in the development of that study.
- David Morrisey expressed concern with the future impervious values. As redevelopment occurs within the City of Denver he indicated there were areas that could be significantly higher impervious values than the current zoning indicates, pointing out that impervious values for single family in Table 2.1 may be too low based on current zoning trends. Both the City of Aurora and City of Denver noted that the future zoning classifications had not been updated in some time and may not reflect the most up to date information. ICON will provide the zoning classification shapefile to Aurora and Denver to review and provide their recommendations on imperviousness values to be used as part of this study.

The team discussed the stream gage located upstream of the mouth of Sand Creek. Morgan previously discussed the stream gage data with Kevin Stewart who indicated he did not believe the data was consistent enough to be used for statistical analysis. Morgan and Shea would have further discussions with Kevin to get more detail regarding the gage validity. They will also review the analysis completed by WWE with the South Platte River CLOMR.

Jeremy Hamer brought up that Denver is very concerned that the peak discharges are lower than anticipated, based on results from a Peak FQ analysis and peak discharge history provided in the report. The Peak FQ analysis from the SPR hydrology CLOMR used 19 years of data leading to wide confidence bands. The Peak FQ 100-yr estimate is 20,080 cfs but has a midpoint of about 30,000 cfs. The existing conditions 100-yr peak of 11,420 is lower than the Peak FQ 95% lower confidence limit. The Peak FQ for the South Platte River CLOMR used the gage at the mouth, it was discussed that the results may be impacted by the location and diversion upstream of the gage.

Denver noted that since 1948 there have been 4 reported discharges close to, or above, the existing conditions 100-yr peak discharges documented in the Draft Hydrology. Two of the historic discharges are higher than the future conditions 100-yr discharge presented in the report.

Denver voiced concern about the double peaks and that it be validated somehow, possibly with gage data. The team discussed obtaining additional stream gage data from USGS or Kevin Stewart since only limited data from these gages online is available online. Jeremy Hamer requested that reason for double peaks be well documented in report and it must be defensible because if the double hydrographs start to coincide or if the peaks fully coincide, the resulting peaks could be significantly higher. Shea mentioned that this is also important because FEMA needs to buy-off as well for the FHAD. David indicated that it is imperative to find the realistic worst case scenario considering everything from here on out depends on the hydrology and requested some sensitivity analysis using different storms on different parts of the basin to see how peak(s) are impacted. For example, a 6-hr storm on the upper part of the basin with 1-hr or 2-hr event on the lower basin, and vice versa. The team discussed the basin size and shape and how storms track in this part of the region. Jeremy Hamer was concerned about storm moving up the basin (south to north), Shea indicated that storms typically move northeasterly but Jeremy Hamer concerned about rare events (for example, how did storms track in the large events such as 1965 and 2013?).

Shea questioned the reduction shown at Colfax Avenue since the only change was a conversion to CUHP 2.0 using NOAA 14 rainfall values. UDFCD noted that a full review of the model had not been completed and would evaluate this area in further detail. Shea noted the 2012 Sand Creek Colfax to Yale FHAD as a comparison and that the 2012 FHAD study used a lower 6 hour rainfall (3.4 in) compared to this study (3.69 in), a 29% decrease was not anticipated. UDFCD and ICON will review this conversion to understand the changes.

To help clarify process of converting each existing study to CUHP v.2.0 / EPA SWMM 5, ICON will provide a technical memo documenting each step and intermediate results of the conversion process. Intermediate results will be provided for converting the existing study to CUHP v.2.0, utilizing a 6-hour rainfall distribution, and then incorporating NOAA 14 rainfall values. Providing results at each step will help the team identify the influence each step of the conversion process had on the overall reduction in peak discharges. The Toll Gate Creek watershed, which included the conversion of three existing studies, was selected to be the subject of the documentation. ICON and UDFCD will discuss any necessary changes to the original scope following the review of the models and technical memo.

There was a consensus that the extent of the effort required for the baseline hydrology has changed now that the report has been submitted and shows a 40% decrease in 100-year peaks. Although we had anticipated that the baseline hydrology was going to be a single iteration, based on the results additional scope will be required to complete the hydrology. Once UDFCD has had an opportunity to compile comments and discuss the gage analysis completed with the South Platte River CLOMR, the Sponsors will discuss next steps for the analysis.

Katie Thompson with the City of Aurora provided background on the Triple Creek Trail project located just upstream of Colfax Avenue. During the hydraulic analysis for the trail project Muller Engineering identified a spill of the 100-year discharge overtopping Colfax Avenue which was not identified in the effective information. The newly identified spill location complicated the floodplain/floodway tie-in. The City was hoping that the new study would help clarify this issue and the floodplain limits around Colfax. The City also noted that they are in process of obtaining a grant for this work and looking at construction early 2018. They asked about the possibility of fast tracking this portion of the FHAD for base information to use in a FEMA CLOMR submittal. It was noted that the FHAD had not yet been initiated. Morgan also expected that it may take to the end of the year to resolve the hydrology. Morgan will have further discussions with the City of Aurora about possible ways to proceed in this area. Denver expressed concern about whether the schedule for completing a CLOMR using revised hydrology could be met considering the complexity of the additional work required to validate the baseline hydrology.

Jay Henke no longer works for City and County of Denver. CCD is hopeful that his replacement will be in place prior to starting Alternatives Analysis where that position's input is crucial.

Next Steps

- The team requested more documentation be provided on the process of converting each existing study to CUHP v.2.0 and NOAA 14 rainfall. Further documentation will be added to the report showing what was changed in each study.
- ICON will document the step by step procedure providing hydrologic results at each step of the conversion process. The technical memo of the conversion process will be included in the appendices of the report.

Action Items:

1. ICON will examine the NOAA 14 isopluvial maps to determine the impact spatially varied rainfall would have on the basin hydrology.
2. ICON will revise the existing impervious values for subwatersheds within the City of Denver and City of Aurora to reflect their impervious layers.
3. ICON will review the land use assumptions in the City of Denver Stormwater Master Plan and compare the impervious values to the recommended USDCM values.
4. City of Aurora and City of Denver will review and provide recommendations on future imperviousness classifications.
5. ICON will provide the technical memo on Toll Gate Creek outlining the step by step conversion procedure.

- END OF MEETING--

To the best of my knowledge, these minutes are a factual account of the business conducted, the discussions that took place, and the decisions that were reached at the subject meeting. Please direct any exceptions to these minutes in writing to the undersigned within ten (10) days of the issue date appearing herein. Failure to do so will constitute acceptance of these minutes as statements of fact in which you concur.

Minutes prepared by: Jeremy Deischer

Jeremy Deischer, EI
ICON Engineering, Inc.

Revised: November 14, 2017

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ICON ENGINEERING, INC.

Sand Creek MDP and FHAD
SIGN-IN SHEET

Date: October 30, 2017

NAME	Organization / Title	Contact Information
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2/2

ICON ENGINEERING, INC.

Sand Creek MDP and FHAD
SIGN-IN SHEET

Date: October 30, 2017

NAME	Organization / Title	Contact Information
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Craig Jacobson	ICON	Phone: E-mail:
Morgan Lynch	UDFCD	Phone: E-mail:
Jeremy Deischer	ICON	Phone: E-mail:
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November 3, 2017

Morgan Lynch, P.E., CFM
Project Manager – Watershed Services
Urban Drainage and Flood Control District
2480 W. 26th Avenue, Suite 156-B
Denver, CO 80211

RE: Sand Creek MDP and FHAD – Toll Gate Creek CUHP Conversion

This memorandum documents the process used to convert the three existing UDFCD studies within Toll Gate Creek to Colorado Urban Hydrograph Procedure (CUHP) v.2.0 with NOAA 14 rainfall values for use within the Sand Creek MDP and FHAD study.

The three existing studies that encompass the Toll Gate Creek Watershed are: East Toll Gate Creek Upper (2010), West Toll Gate Creek (2013), and Toll Gate Creek and East Toll Gate Creek (2013). Although the West Toll Gate Creek hydrologic model covers the main stem of Toll Gate Creek, the model was truncated to only model West Toll Gate Creek. Inflows from East Toll Gate Creek Upper and West Toll Gate Creek were represented in the Toll Gate Creek and East Toll Gate Creek model by inflow hydrographs for each scenario.

Existing studies were first executed using the original versions of CUHP and EPA SWMM. Peak flow results before any conversion for Upper East Toll Gate Creek, West Toll Gate Creek, and East Toll Gate Creek and Lower Toll Gate Creek can be found in Table 1 for Scenarios 0, 10, and 20, respectively.

Basin parameters for each study were then transferred to the CUHP v.2.0 worksheet. No calibration factors (Cp or Ct) used in prior studies were carried forward in the conversion process. One modification was made to the parameters for Toll Gate Creek and East Toll Gate Creek. The Horton's Decay Coefficient was adjusted to a more typical value of 0.0018 1/seconds for all subwatersheds.

Varying rainfall distributions were used in the existing studies. For all subbasins in East Toll Gate Creek Upper a 2-hour rainfall distribution was used. West Toll Gate Creek used a 2 hour rainfall distribution for drainage areas less than 10 square miles, and a 6 hour distribution for drainage areas greater than 20 square miles. Toll Gate Creek and East Toll Gate Creek used a combination of 2-, 3-, and 6-hour rainfall distributions. CUHP v.2.0 no longer provides the option for a 3-hour rainfall distribution. Any subbasins that used a 3-hr distribution in the existing study was revised to a 6-hour distribution in Scenario 21 and 22. Peak flow results using the NOAA Atlas 2 rainfall values and rainfall distributions used in the existing studies with EPA SWMM 5.1 can be found in Table 1, Scenarios 1, 11, 21.

Rainfall values were updated to NOAA 14 point precipitation values maintaining the rainfall distribution and area adjustment factors used in the existing studies. The NOAA Atlas 14 point precipitation values for the centroid of the Sand Creek Basin are 2.44 for the 1-hour rainfall depth and 3.69 for the 6-hour rainfall depth. As previously mentioned, any subbasins in the Toll Gate Creek and East Toll Gate Creek study that previously used a 3-hr rainfall distribution was converted to use a 6-hour rainfall distribution for interim Scenarios 21, and 22. The peak flow results after converting NOAA 14 point precipitation values maintaining existing rainfall distributions can be found in Table 1, Scenarios 2, 12, 22.

Studies were then updated to use a 6-hr rainfall distribution for all subbasins. The depth area adjustment factor was revised in CUHP to reflect modeling of the entire Sand Creek Basin, approximately 180 square miles. Peak flow results can be found in Table 1, Scenario 3, 13, 23.

Sincerely,

Craig Jacobson, P.E., CFM
Principal

Jeremy Deischer, EI
Project Engineer

Cc: Shea Thomas, P.E.
Watershed Services Manager

Table 1: 100-year Future Conditions CUHP Conversion

Study Name	Scenario	CUHP Version	Source of Rainfall	Rainfall Distribution	EPA SWMM Version	1-hr Rainfall (in)	6-hr Rainfall (in)	DARF (sq. mi)	SWMM Discharge (cfs)
Upper East Toll Gate Creek	0	v.1.3.1	NOAA 2	2-hr	5.0	2.66	--	--	1061
	1	v.2.0.0	NOAA 2	2-hr	5.1	2.66	--	--	1033
	2	v.2.0.0	NOAA 14	2-hr	5.1	2.44	--	--	912
	3	v.2.0.0	NOAA 14	6-hr	5.1	2.44	3.69	180	623
West Toll Gate Creek	10	v.1.3.3	NOAA 2	6-hr	5.0	2.66	3.4	21	15546
	11	v.2.0.0	NOAA 2	6-hr	5.1	2.66	3.4	21	13707
	12	v.2.0.0	NOAA 14	6-hr	5.1	2.44	3.69	21	12118
	13	v.2.0.0	NOAA 14	6-hr	5.1	2.44	3.69	180	9322
East Toll Gate Creek and Lower Toll Gate Creek [1]	20	v.1.3.3	NOAA 2	2-, 3-, 6-hr	5.0	2.66	3.4	Varies	23013
	21	v.2.0.0	NOAA 2	2-, 6-hr [2]	5.1	2.66	3.4	Varies	20612
	22	v.2.0.0	NOAA 14	2-, 6-hr [2]	5.1	2.44	3.69	Varies	18717
	23	v.2.0.0	NOAA 14	6-hr	5.1	2.44	3.69	180	13560

1 Each iteration of East Toll Gate Creek uses inflow hydrographs from the respective scenario for Upper East Toll Gate Creek and West Toll Gate Creek (Scenario 20 uses 0, and 10. Scenario 21 uses 1, 11, etc.)

2 3 hour storm distributions were removed with the update to USDCM and CUHP v.2.0. All basins which previously used 3-hr distributions used 6-hr distributions with a DARF of 21 sq miles

Sand Creek MDP & FHAD
Hydrology Progress Meeting
December 19, 2017 2:30 PM

UDFCD Offices
Meeting Minutes

Attendees:		
	Curtis Bish,	*City of Aurora – PROS*
	Craig Perl,	*City of Aurora – Public Works*
	Katie Thompson,	*City of Aurora*
	Jon Villines,	*City of Aurora – Water*
	Andrew Pihaly,	*City of Commerce City*
	Jeremy Hamer,	*City of Denver – Floodplain*
	David Morrisey,	*City of Denver – Floodplain*
	Sam Pavone,	*City of Denver – Wastewater CPM*
	Morgan Lynch,	*Urban Drainage and Flood Control District*
	Shea Thomas,	*Urban Drainage and Flood Control District*
	Craig Jacobson,	*ICON Engineering*
	Jeremy Deischer,	*ICON Engineering*

The purpose for this meeting was to address prior questions and comments on the draft hydrology report submission, to present subsequent hydrology evaluations completed by ICON and the UDFCD following the previous meeting, and to obtain feedback from project sponsors on the updated hydrology results.

Revised Basin Imperviousness

- ICON reviewed the different zoning classifications in the study area for each jurisdiction. Each zoning classification was grouped into a land use category within the Urban Storm Drainage Criteria Manual. The percent impervious values for each land use classification were adjusted to correlate better with the previous studies for each jurisdiction. In the City of Denver and Commerce City, the future percent impervious values were carried forward from the City and County of Denver Storm Drainage Master Plan. Values from the Original Aurora study were used within the City of Aurora. Values from these studies were generally higher for residential zoning increasing the average future basin imperviousness for the watershed by approximately 12 percent.
- The basis to determine existing impervious values for City of Aurora and City of Denver subwatersheds was revised from using National Land Cover Dataset (NLCD) to GIS planimetric shapefiles. The NLCD will still be used for subwatersheds within Commerce City. The planimetric data increased the existing imperviousness for some subwatersheds but also decreased some subwatersheds compared to the NLCD.

Comparison of Watershed Percent Impervious Values				
	Draft Hydrology Report		Revised Basin Imperviousness	
Basin Name	Existing (NLCD)	Future (USDCM % Impervious)	Existing (Commerce City - NLCD, Aurora and Denver - Planimetric GIS Data)	Future (Commerce City / Denver - Denver MP, Aurora - Original Aurora)
B010	61	76	61	94
B020	64	76	61	93
B025	42	50	49	60
B030	53	56	44	67
B035	61	65	52	78
B040	59	76	51	79
B050	40	42	41	54
B060	37	46	35	61
B070	28	43	24	53

Rainfall Point Precipitation Distribution and Isopluvials

- ICON explained the approach taken to determine how spatially varied the design rainfall was throughout the watershed. The NOAA 14 isopluvials were first examined to see the spatial variation of rainfall. For both the 1-hour and 6-hour design storm the watershed generally fell within one NOAA 14 isopluvial zone. Using the NOAA 14 Point Precipitation Server 1-hour, and 6-hour values were obtained for the mouth, the centroid, and the headwaters of the Sand Creek Basin. The 1-hour and 6-hour rainfall value for each existing study was also obtained to determine the spatial variation throughout the watershed. The point precipitation used at the centroid of Sand Creek for the draft baseline hydrology, 2.44 inches and 3.69 inches respectively, were higher than all but one other location. The Murphy Creek NOAA 14 1-hr, and 6-hour rainfall depths were 0.02 inches and 0.01 inches higher, respectively. The 1-hr and 6-hr rainfall point precipitation values at the centroid of Sand Creek will be carried forward and rainfall will not be spatially varied for each study.

	NOAA 2 Rainfall (in)		NOAA 14 Rainfall (in)	
Location	1-hr	6-hr	1-hr	6-hr
Sand Creek Mouth	--	--	2.4	3.51
Sand Creek Centroid	--	--	2.44	3.69
Centroid - Sand Creek FHAD (2012)	2.65	3.4	2.4	3.65
Sand Creek Headwaters	--	--	2.36	3.63
Baranmor Ditch	2.59	--	2.42	3.57
Toll Gate Creek	2.66	3.4	2.43	3.69
East Toll Gate Creek	2.66	--	2.43	3.69
West Toll Gate Creek	2.66	--	2.43	3.69
Sand Creek Right Bank	2.62	--	2.44	3.61
Murphy Creek FHAD (2006)	2.65	3.4	2.46	3.7
Westerly Creek MDP (2015)	2.58	--	2.37	3.59

Summary of Model Approach

- Following the previous progress meeting, ICON prepared a memo detailing each step of the conversion process for Toll Gate Creek. The table summarizing the peak flow results for each step was presented to the group. The Toll Gate Creek study was comprised of three studies, Upper East Toll Gate Creek, West Toll Gate Creek, and East Toll Gate Creek and Lower Toll Gate Creek. Scenario 0, 10, and 20 represented the analysis of the original existing study. Scenario 1, 11, and 21 converted the studies to

CUHP v.2.0 maintaining the NOAA Atlas 2 rainfall values. All basin calibration factors used in previous studies were not carried forward in the conversion process. Converting the studies to CUHP v.2.0 reduced the peak discharge an average of eight percent for the three studies.

- Scenario 2, 12, and 22 incorporated NOAA Atlas 14 point precipitation values but maintained the rainfall distributions used in the existing studies. The rainfall conversion reduced the peak discharges an average of 11 percent from the prior Scenario's (1, 11, and 21) and an average of 18 percent from the existing studies peak discharge.
- Scenario 3, 13, and 23 used a 6-hr rainfall distribution for each study with a depth area reduction factor for the 180 square mile watershed. Converting the rainfall to a 6-hour rainfall distribution reduced the peak discharges an average of 27 percent from Scenario's 2, 12, and 22. The conversion process from the existing studies to CUHP v.2.0 and a 6-hour NOAA 14 rainfall distribution reduced the peak flow an average of 41 percent for the Toll Gate Creek Watershed.
- It was noted that Scenario's 20-23 used inflow hydrographs from the upstream studies so the reduction in peak discharge was not solely from the conversion of the East Toll Gate Creek and Lower Toll Gate Creek study.
- Craig noted the depth area reduction factors had been revised as part of the CUHP v.2.0 re-calibration process.

Peer Review

- Morgan informed the team that following the prior meeting, she had met with Kevin Stewart of UDFCD regarding the stream gage information, Andrew Earles of Wright Water Engineers on the PeakFQ Analysis of Sand Creek that was done as part of the South Platte River Hydrology CLOMR, and Gerald Blackler of Enginuity Engineering Solutions who was involved in the recalibration effort of CUHP v.2.0. The memo summarizing the findings of the peer review can be found in the attached memo.
  - Morgan spoke to Kevin Stewart about the validity of the stream gage near the mouth of Sand Creek and historic stream gage records to validate the double peak seen in the rainfall-runoff model. Morgan informed the team that continuous stream gage records were not available for this gage. Even though Sand Creek is a dynamic sand bed system that may impact the accuracy of stream gage readings it was agreed that the stream gage is the best available information and should be included in the analysis. Morgan presented to the group peak flow results from the 1965 flood event. Upstream of the confluence of Sand Creek and Toll Gate Creek a peak flow of 17,000 cfs was recorded on Toll Gate Creek at 6th Avenue, with a peak flow of 13,400 cfs on Sand Creek at Sable Blvd. The peak flow downstream of the confluence was recorded at 18,900 providing evidence that the peaks of the two drainageways did not coincide.
  - Morgan discussed the PeakFQ analysis that Wright Water Engineers did on the Sand Creek stream gage with Andrew Earles. The analysis used 19 years of stream gage records from 1993 – 2013. The PeakFQ estimated the 100-year

discharge on Sand Creek near the mouth to be 20,080 cfs with a 95% confidence interval ranging from 11,960 – 48,090 cfs.

Gerald Blacker was consulted on the whether CUHP v.2.0 was appropriate to use to develop a rainfall-runoff model for a watershed this large. Four different scenarios were compared at Colfax Avenue to examine the total 100-year peak flow and unit discharges for each scenario. The four scenarios were: CUHP 1.3.1 with SWMM 5, CUHP 2.0.0 with SWMM 5, USGS Stream Stats, and CUHP 2.0.0 using a historic two percent imperviousness. Based on the findings of his analysis it was determined CUHP v.2.0 was appropriate to use for a rainfall-runoff model for the Sand Creek study.

Rainfall Distribution for Lower Watersheds

- ICON described two additional scenarios to determine the impact of using the 6-hour rainfall distribution on the lower subwatersheds. The first scenario used a 2-hour rainfall distribution on the lower 10 square miles of tributary watersheds. Modifying the rainfall distribution to a 2-hour storm removes any depth area reduction factors that would be applied to a 6-hour storm distribution. This adjustment increased the peak flow of the downstream watershed but led to an overall decrease peak flow at the mouth of Sand Creek.
- The second rainfall scenario used a 2-hour rainfall distribution for all subwatersheds created as part of the Sand Creek MDP and FHAD, approximately 16.8 square miles. This scenario shortened the time to peak of the lower watersheds, further reducing the peak flow at the mouth of Sand Creek.

Hydrograph Timing and Sensitivity Analysis

- Craig Jacobson explained the six hydrologic scenarios to determine the impact on the 100-year future conditions peak flow. Revising the impervious values (Scenario 2) increased the peak flow from 17,168 cfs to 17,243 cfs. Scenario 3 adjusted the rainfall of the lower 10 square mile watersheds to a 2-hour rainfall distribution. The 2-hr rainfall distribution for the lower watershed reduced the 100-year peak flow to 17,058 cfs. Scenario 4 adjusted all of the watersheds created by ICON (~16.8 sq. mi) to a 2-hour rainfall distribution further reducing the 100-year peak flow to 16,666 cfs. In Scenario 5 the timing of Toll Gate Creek was delayed 4 hours for the peaks on Toll Gate Creek and Sand Creek to coincide increasing the peak discharge to 23,563 cfs. Scenario 6 delayed the lower watersheds 6-hours to model if the peaks of the lower watersheds coincided with the Scenario 5 peak. Scenario 6's peak flow rate increased to 29,786 cfs extremely similar to the FIS discharge of 30,500 cfs.
- The team discussed the possibility of Scenario 5 occurring with the peak of the Toll Gate Creek hydrograph coinciding with the Sand Creek peak flow. The resulting peak flow in Scenario 5 of 23,563 cfs aligned closer to the PeakFQ analysis and was more centered within the 95% confidence intervals than the draft baseline hydrology.
- The team discussed the flood history section in the draft baseline report detailing the recorded peak flows of prior flood events along Sand Creek. A peak discharge of 25,000 cfs was estimated during the 1957 flood event near Stapleton International Airport. In the 1965 flood event Sand Creek was estimated to have a peak discharge of 18,900 cfs. The stream gage near the moth recorded a peak discharge of 14,900 cfs during the 2013 flood event, the largest discharge in the PeakFQ analysis.

- Jeremy Hamer noted that the Scenario 5 discharge was also more justifiable from the floods of record. The peak discharge presented in the draft baseline hydrology had been very close to or exceeded several times in the known flood history of Sand Creek.
- The team suggested that in reviewing all of the data, the hydrology approach presented with Scenario 5 appeared the most reasonable, as this data appeared best validated by the stream gage analysis results and documented historic flow data. In addition the increase in the recommended flow (23,563 cfs) versus the PeakFQ findings of 20,080 cfs could be supported by the future land use assumptions used in the CUHP modeling.
- In general, the group appeared more comfortable with the results and with the additional data presented.
- Jeremy Hamer noted that this additional analysis along with more detailed documentation of the process used to prepare the baseline hydrology provides support for and helps validate the results and should be included in the report. He requested to look into the material further before making any final decisions on the hydrology approach. ICON will provide the sponsors the hydrologic models to review before moving forward.
- David Morrisey commented on the significant reduction in peak discharge after incorporating the depth area reduction factor. Shea explained the reduction in discharge was to be expected as storm centers are not the size of a watershed this large, necessitating the reduction in rainfall point precipitation. David said using the PeakFQ analysis to validate the rainfall-runoff model made him more comfortable with the hydrologic results.
- Morgan asked for all comments by January 10th.

Triple Creek Trail

- Katie Thompson asked the team when the hydrology would be finalized and be ready for use in the Triple Creek Trail project located just upstream of Colfax Avenue. As discussed in the previous meeting, Muller Engineering has identified a spill of the 100-year discharge overtopping Colfax Avenue not identified in the effective information. This newly identified spill location complicates the floodplain / floodway tie-in. Morgan mentioned that due to the difference in flows between the old and new study, the hydrology would need to be reconciled to make a smooth transition. She will discuss this further with Terri Fead at the District for recommendations. For now both Morgan and Craig anticipated that the upstream discharge at Piccadilly (~16,000cfs) could be extrapolated until increasing at the Toll Gate Creek confluence; but this will be reviewed further. It was noted that the baseline hydrology is behind schedule as a result of the MDP / FHAD not getting started as early as originally planned. Denver recognized the benefit of having revised hydrology for the Triple Creek Trailhead CLOMR, but warned against allowing the MDP / FHAD process to be rushed by the Triple Creek Trail CLOMR schedule. Use of the hydrology developed for the MDP / FHAD may be used in the Triple Creek Trail CLOMR once it's accepted by all parties.
- It was suggested that Katie coordinate with Muller to determine the overtopping discharge at Colfax and how that may relate to the final hydrology determination for the

area. Morgan also offered to be involved in any discussion with Muller to help determine the best approach for moving forward with the CLOMR to meet the City's timeline.
- ICON was not under scope yet for the FHAD, as the group was waiting for the completion of the hydrology; however ICON will be beginning that effort soon and may be able to provide updated cross-section information for the City in the Triple Creek Trail area ahead of the other FHAD locations.
- ICON requested any information that the City had from Muller to keep these work products consistent.

Other

Jon Villines asked about the scope of any potential floodplain changes to other drainageways with the reduced discharges, specifically Toll Gate Creek. Jon informed the group the City of Aurora has ongoing projects to mitigate the floodplain based on the existing study discharges and floodplain delineation. Shea stated the scope of this study is to only study the floodplain of Sand Creek.

Action Items:

1. ICON will provide the team the hydrologic models of the 6 scenarios to review.
2. The team will provide comments to Morgan by January 10th.
3. Aurora will provide ICON the cross sections developed by Muller Engineering just upstream of Colfax Avenue to include in the FHAD development

- END OF MEETING--

To the best of my knowledge, these minutes are a factual account of the business conducted, the discussions that took place, and the decisions that were reached at the subject meeting. Please direct any exceptions to these minutes in writing to the undersigned within ten (10) days of the issue date appearing herein. Failure to do so will constitute acceptance of these minutes as statements of fact in which you concur.

Minutes prepared by: Jeremy Deischer

Jeremy Deischer, P.E.
ICON Engineering, Inc.

Revised:
January 3, 2018

MEMORANDUM

TO: ICON Engineering

FROM: Morgan Lynch

SUBJECT: Sand Creek Gage Information and CUHP Validation

DATE: December 5, 2017

The purpose of this technical memorandum for the *Sand Creek Downstream of Colfax Flood Hazard Delineation (FHAD) and Major Drainageway Plan (MDP)* (Study) is to document the previous storm event data available at the USGS Gage Site, Sand Creek at Mouth near Commerce City (USGS 394839104570300) and Sand Creek Above Burlington Ditch near Commerce City (USGS 06714360). In addition to the gage data, this memorandum documents the anticipated impact of preparing rainfall-runoff models with UDFCD CUHP Version 2.0.0 (UDFCD, 2016).

Stream Gage Analysis

The two USGS gages located along Sand Creek have had continuous annual records. The gage located at the mouth of Sand Creek, near the confluence with the South Platte River, has a gage record of 25 years, including a recorded peak flow estimate of 14,900 cfs in September 2013. The USGS gage upstream of the Burlington Ditch has a shorter period of record of 4 years and has not been included in recent statistical analyses. Wright Water Engineers, Inc. preformed a flood frequency analysis to support the South Platte River CLOMR (2011) using 19 years of record available at the time from the gage at the mouth. That analysis followed the methods described in the document *Guidelines for Determining Flood Flow Frequency* published by USGS, commonly known as *Bulletin 17*. The results estimated 20,000 cfs for the 100-year recurrence interval. The results of the frequency analysis are provided as an attachment to this memorandum.

The location of the Sand Creek gage at the mouth may result in some inconsistencies in the gage data. The gage is located near the confluence with the South Platte River and may be influenced by the tailwater condition from the South Platte River. In addition, Sand Creek is a sand bottom channel which presents challenges when determining the stage during flow events due to the dynamic nature of the system. Due to the physical conditions surrounding the gage, it would be appropriate to assume a rainfall- runoff model would result in flow rates that fall within the lower confidence limits of the flood frequency analysis for the USGS gage.

Colorado Unit Hydrograph Procedure (CUHP)

UDFCD recently completed a revision to the proprietary rainfall-runoff software, CUHP. The previous version of CUHP (Version 1.3.1) was upgraded to Version 2.0.0 in 2016. This version included a re-calibration study that modified the underlying Unit Hydrograph shaping parameters. The re-calibration effort was based on numerous historical gage records located in the UDFCD Boundary. In addition, a policy change was made to utilize point rainfall data as documented in *NOAA Atlas 14*, Volume 8 (2013). The re-calibration did not adjust routing from Kinematic to Dynamic Wave, instead these dampening effects were accounted for in Version 2.0.0 through modification of peaking and timing parameters to better represent runoff reflected in gage records. As such, the larger and longer a watershed, the more these changes will compound. This may result in a larger reduction along the main stem of Sand Creek than what has been determined in the tributary areas. (Blackler, 2017)

To validate the lower results for the 100-year storm event along Sand Creek, a comparison analysis was completed along Sand Creek at Colfax Avenue. This location was chosen because a hydrologic update for the upper watershed to this point was recently completed and a complete, approved model was available. The following items were used for comparison:

1. Compare CUHP Version 1.3.1 to Version 2.0.0
2. Estimate Peak Flows at a USGS Gage on Sand Creek using Bulletin 17B methods.
3. Estimate Peak Flows for the Foothill Regions under USGS Stream Stats
4. Develop a Historic CUHP Version 2.0.0 Model to Compare to (3) above.

The results of this comparison are summarized in **Table 1** below. Based on these comparisons, it is appropriate to assume CUHP 2.0.0 is an appropriate rainfall-runoff model for this size of hydrologic study.

TABLE 1
Comparison of Model Discharges along Sand Creek at Colfax Avenue

Method	Area	100 Yr Peak Flow (cfs)	Unit Discharge (cfs/sq mi)
CUHP 1.3.1 and SWMM 5 (Matrix, 2013)	92	19,245	210
CUHP 2.0.0 and SWMM 5	92	15,000	164
Bulletin 17B (WWE, 2011) *	187	20,000	107
USGS Stream Stats - Sand Creek at Colfax	105	8,450	80
CUHP 2.0.0 and SWMM 5 **	92	8,733	95
* At Sand Creek at Mouth (USGS) ** (Historic 2% Imp) This is to compare with Foothills Region Stream Stats above			

Sand Creek at Mouth near Commerce City, CO
USGS 394839104570300

```
                              PEAKFQ PEAK FLOW DATA.PRT
1
  Program PeakFq          U. S. GEOLOGICAL SURVEY             Seq.002.000
  Version 7.1        Annual peak flow frequency analysis      Run Date / Time
  3/14/2014                                                   07/14/2015 12:00

                          --- PROCESSING OPTIONS ---

                       Plot option         = None
                       Basin char output   = None
                       Print option        = Yes
                       Debug print         = No
                       Input peaks listing = Long
                       Input peaks format  = WATSTORE peak file

                       Input files used:
                          peaks (ascii)  - C:\Users\stillack\Desktop\Test\PEAKFQ PEAK
FLOW DATA.TXT
                          specifications -
C:\Users\stillack\Desktop\Test\PKFQWPSF.TMP
                       Output file(s):
                          main - C:\Users\stillack\Desktop\Test\PEAKFQ PEAK FLOW
DATA.PRT

1


  Program PeakFq          U. S. GEOLOGICAL SURVEY             Seq.001.001
  Version 7.1        Annual peak flow frequency analysis      Run Date / Time
  3/14/2014                                                   07/14/2015 12:00

       Station - 394839104570300  SAND CREEK AT MOUTH NR COMMERCE CITY,CO


                     I N P U T   D A T A   S U M M A R Y

                 Number of peaks in record           =       19
                 Peaks not used in analysis          =        0
                 Systematic peaks in analysis        =       19
                 Historic peaks in analysis          =        0
                 Beginning Year                      =     1993
                 Ending Year                         =     2013
                 Historical Period Length            =        0
                 Generalized skew                    =   -0.126
                      Standard error                 =    0.550
                      Mean Square error              =    0.303
                 Skew option                         = STATION SKEW
                 Gage base discharge                 =      0.0
                 User supplied high outlier threshold =   --
                 User supplied PILF (LO) criterion    =   --
                 Plotting position parameter         =     0.00
                 Type of analysis                      BULL.17B
                 PILF (LO) Test Method                      GBT
                 Perception Thresholds           =   Not Applicable
                 Interval Data                   =   Not Applicable


  *********  NOTICE  --  Preliminary machine computations.       *********
  *********  User responsible for assessment and interpretation.  *********

    WCF134I-NO SYSTEMATIC PEAKS WERE BELOW GAGE BASE.                    0.0
    WCF162I-SYSTEMATIC PEAKS EXCEEDED HIGH-OUTLIER CRITERION.   1   10507.1
    WCF195I-NO LOW OUTLIERS WERE DETECTED BELOW CRITERION.            486.8
                                      Page 1
```

*WCF151I-17B WEIGHTED SKEW REPLACED BY USER OPTION. 0.424 1.545 -1

Kendall's Tau Parameters

	TAU	P-VALUE	MEDIAN SLOPE	No. of PEAKS
SYSTEMATIC RECORD	0.345	0.042	80.000	19

1

Program PeakFq U. S. GEOLOGICAL SURVEY Seq.001.002
Version 7.1 Annual peak flow frequency analysis Run Date / Time
3/14/2014 07/14/2015 12:00

Station - 394839104570300 SAND CREEK AT MOUTH NR COMMERCE CITY,CO

ANNUAL FREQUENCY CURVE PARAMETERS -- LOG-PEARSON TYPE III

	FLOOD BASE		LOGARITHMIC		
	DISCHARGE	EXCEEDANCE PROBABILITY	MEAN	STANDARD DEVIATION	SKEW
SYSTEMATIC RECORD	0.0	1.0000	3.3544	0.2825	1.545
BULL.17B ESTIMATE	0.0	1.0000	3.3544	0.2825	1.545

BULL.17B ESTIMATE OF MSE OF AT-SITE SKEW 0.6169

ANNUAL FREQUENCY CURVE -- DISCHARGES AT SELECTED EXCEEDANCE PROBABILITIES

ANNUAL EXCEEDANCE PROBABILITY	BULL.17B ESTIMATE	SYSTEMATIC RECORD	<-- FOR BULLETIN 17B ESTIMATES --> VARIANCE OF EST.	95% CONFIDENCE INTERVALS LOWER	UPPER
0.9950	1002.	1002.	----	659.8	1332.0
0.9900	1017.	1017.	----	672.4	1350.0
0.9500	1096.	1096.	----	739.9	1442.0
0.9000	1174.	1174.	----	807.8	1535.0
0.8000	1325.	1325.	----	939.5	1714.0
0.6667	1550.	1550.	----	1138.0	1987.0
0.5000	1927.	1927.	----	1467.0	2466.0
0.4292	2145.	2145.	----	1654.0	2759.0
0.2000	3529.	3529.	----	2745.0	4877.0
0.1000	5378.	5378.	----	4017.0	8288.0
0.0400	9182.	9182.	----	6319.0	16760.0
0.0200	13620.	13620.	----	8733.0	28440.0
0.0100	20080.	20080.	----	11960.0	48090.0
0.0050	29470.	29470.	----	16270.0	81030.0
0.0020	48660.	48660.	----	24270.0	160700.0

1

Program PeakFq U. S. GEOLOGICAL SURVEY Seq.001.003
Version 7.1 Annual peak flow frequency analysis Run Date / Time
3/14/2014 07/14/2015 12:00

Station - 394839104570300 SAND CREEK AT MOUTH NR COMMERCE CITY,CO

I N P U T D A T A L I S T I N G

WATER YEAR	PEAK VALUE	PEAKFQ CODES	REMARKS
1993	1210.0		
1994	1550.0		
1996	1230.0		
1997	5750.0		
1998	1390.0		
2000	2060.0		
2001	2190.0		
2002	1510.0		
2003	1190.0		
2004	4150.0		
2005	2660.0		
2006	1260.0		
2007	2080.0		
2008	1620.0		
2009	2020.0		
2010	3190.0		
2011	4380.0		
2012	1840.0		
2013	14900.0		

Explanation of peak discharge qualification codes

PeakFQ CODE	NWIS CODE	DEFINITION
D	3	Dam failure, non-recurrent flow anomaly
G	8	Discharge greater than stated value
X	3+8	Both of the above
L	4	Discharge less than stated value
K	6 OR C	Known effect of regulation or urbanization
H	7	Historic peak

- Minus-flagged discharge -- Not used in computation
  -8888.0 -- No discharge value given
- Minus-flagged water year -- Historic peak used in computation

1

Program PeakFq U. S. GEOLOGICAL SURVEY Seq.001.004
Version 7.1 Annual peak flow frequency analysis Run Date / Time
3/14/2014 07/14/2015 12:00

Station - 394839104570300 SAND CREEK AT MOUTH NR COMMERCE CITY,CO

EMPIRICAL FREQUENCY CURVES -- WEIBULL PLOTTING POSITIONS

WATER YEAR	RANKED DISCHARGE	SYSTEMATIC RECORD	B17B ESTIMATE
2013	14900.0	0.0500	0.0500
1997	5750.0	0.1000	0.1000

2011	4380.0	0.1500	0.1500
2004	4150.0	0.2000	0.2000
2010	3190.0	0.2500	0.2500
2005	2660.0	0.3000	0.3000
2001	2190.0	0.3500	0.3500
2007	2080.0	0.4000	0.4000
2000	2060.0	0.4500	0.4500
2009	2020.0	0.5000	0.5000
2012	1840.0	0.5500	0.5500
2008	1620.0	0.6000	0.6000
1994	1550.0	0.6500	0.6500
2002	1510.0	0.7000	0.7000
1998	1390.0	0.7500	0.7500
2006	1260.0	0.8000	0.8000
1996	1230.0	0.8500	0.8500
1993	1210.0	0.9000	0.9000
2003	1190.0	0.9500	0.9500

1

End PeakFQ analysis.
Stations processed : 1
Number of errors : 0
Stations skipped : 0
Station years : 19

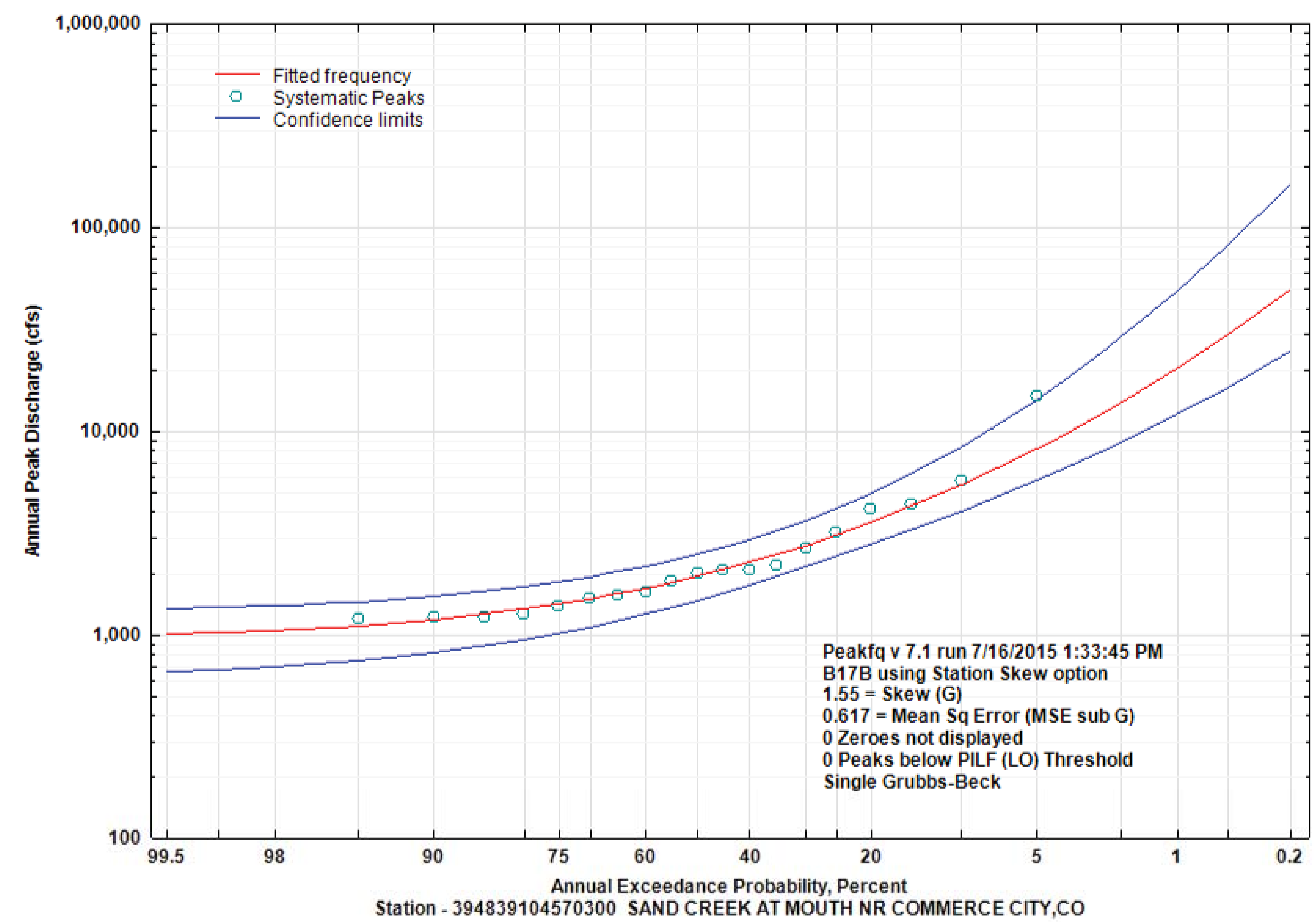
Data records may have been ignored for the stations listed below.
(Card type must be Y, Z, N, H, I, 2, 3, 4, or *.)
(2, 4, and * records are ignored.)

For the station below, the following records were ignored:

FINISHED PROCESSING STATION: 394839104570300USGS SAND CREEK AT MOUTH NR COMMER

For the station below, the following records were ignored:

FINISHED PROCESSING STATION:



Draft Baseline Hydrology Comments

Sponsor	PDF Report Page Number	Comment	ICON Response
UDFCD - Morgan	4	I would really like to incorporate the goals of the masterplan as communicated by the Sponsors in the kickoff meeting in the MDP report. It will be a good snapshot of what was important at the time and we can clearly look back at the goals and objectives as we move through the process.	The goals of the masterplan, as described by the the Sponsors in the kickoff meeting, have been added to the purpose and scope section of the report
City of Denver	4	The "surface" that will be used for this study, for hydraulic modeling and flood hazard mapping, must be based on the original LiDAR source data, rather than creating a TIN from contours. The LiDAR data included contours and raw LiDAR points. The surface for this study should be either the original contours provided with the LiDAR data, or a surface created from the original LiDAR point data and contours that are based on that surface. Please clarify.	The surface used to develop the FHAD will be the source DEM provided by FEMA and not a TIN from the contour polylines derived from the DEM.
City of Aurora	6	We would prefer to use our Planimetrics data for MDPs and OSPs, including this one. We believe we should be using the best available data for each jurisdiction. We purchased and maintain this data so that it could be used for purposes such as this.	The existing conditions imperviousness has been revised to be based on the available planimetric data for the City of Aurora and City of Denver.
City of Denver	6	We should review the percent impervious values used in the model. The City of Denver GIS group is or has sent an updated impervious layer to ICON. How do these values and those of the Denver Storm Drainage Masterplan compare to those used for the model and how does this affect the results?	The future percent impervious for each zoning designation was revised based on discussions with the Sponsors
UDFCD-Shea	6	How? Open space = 2% Water bodies = 100% Other adjustments? [Comment pertained to reclassifying the NLCD for existing conditions analysis]	The NLCD raster was reclassified in several areas to account for development since the NLCD was published. This statement is no longer valid and was removed from the report since the planimetric data is now being used for existing conditions analysis in the City of Denver and City of Aurora
	6	Please expand to include area of each land use and also define by jurisdiction.	The table has been expanded to show the percent of land use for each jurisdiction and basinwide
City of Denver	7	3 (There is a new gage U/S of the Burlington Diversion, USGS 06714360, that has a period of record of 2013-2016.	The report has been revised to include information about the thrid stream gage
UDFCD - Morgan	7	We will need to expand the gage discussion based on discussions with Kevin.	Information from the memo provided by UDFCD on the stream gage analysis has been included in the report
UDFCD - Shea		This figure [2-2] is fine for showing the subwatersheds, but there should be a separate figure showing the Study Area that clearly labels some of the features in the narrative (highlighted).	An additional figure was added to highlight key features within the study area
City of Aurora	8	Please label Colfax and the boundary of this study.	The boundary of this study at Colfax Avenue was labeled
UDFCD - Morgan	9	Recommend providing dates for the studies here ie Westerly Creek (2015) to point to the reference.	Dates for each of the existing studies has been added to help point to the reference
City of Denver	9	Instead of using a single point for a 181 sq-mi watershed, please check area-weighted rainfall depth by overlaying basin area over isohyetal contours.	A table was added to the report showing the spatially varied point precipitation rainfall values throughout the basin
UDFCD-Morgan	9	State the reduction factor applied?	A table detailing the Depth Reduction Factor used in this study has been added to the report
City of Aurora	9	This info was not in the model provided?	The Original Aurora and Peoria Street Basin were provided to the project team. The basin delineations for the Original Aurora and Westerly Creek FHAD significantly overlapped so the Orginial Aurora study area was summarized into one basin for the Sand Creek study.
City of Denver	9,10	Insert into this report.	The requested table and figures referenced from the USDCM have been included in the report text
City of Denver	10	Was this done for subwatersheds and updated on the other studies? If other studies were not "updated," note whether other studies are based in this methodology.	A statement clarifying no adjustment to the existing studies has been added to the report

Draft Baseline Hydrology Comments

Sponsor	PDF Report Page Number	Comment	ICON Response
City of Aurora	10	What are the two different scenarios?	The two different population scenarios are described further in the text, 600,000 and 900,000 people
City of Aurora	10	Is this the typical method for representing drop structures in the hydraulic model?	Yes, correcting the slope of the channel to better model the conveyance slope is the standard approach of modeling an open channel in SWMM
UDFCD - Shea	10	While there are differences in the modeling efforts, we are suggesting a significant reduction of flowrates. We must be able to reconcile those new flows using all information possible, including the previous studies and historic records, and to explain why the new data and models would produce different results.	Additional detail has been added to the report about the steps taken to reconcile the flows and the effective discharges
UDFCD - Morgan	10	This statement may be overly broad, would recommend removing and provide comparisons.	The statement has been removed from the report.
UDFCD - Shea	11	Also include these columns: Study Name, Watershed Area, Original CUHP Peak Timing, CUHP v2.0 Peak Timing	The requested columns have been added to the report
UDFCD - Morgan	11	Note changes made to the original model.	Columns have been added to the table indicating the changes to each of the existing study
City of Denver	11	Do these correspond to numbers on Figure 3-1? If so, add to table.	The table has been revised to include the ID on Figure 3-1
UDFCD - Shea	13	Because of this double peak, we need to analyze a storm centered over the lower portion of the watershed. This model would use 2-hr rainfall for the portion of the watershed in the lower 10 square miles, and 6-hr rainfall for the rest of the watershed.	Text has been included in the report about the different scenarios that were analyzed following the draft baseline report submittal.
City of Denver	13	Label subwatersheds.	Subwatershed labels have been added
City of Denver	13	Validate double peaks (typ.)	The double peaks shown in the draft baseline report have been revised based on further analysis and discussion with the project team
UDFCD - Shea	19	Make the stream layer more prominent. Can you reduce the number of labeled streets?	The symbology of the streams were revised and only major roadways (Highway, Arterials, Collectors) were labeled
UDFCD - Morgan	14	I would add soil reference all site all the previous reports that hydrographs were extracted	All existing studies have been added to the references section
UDFCD - Morgan	19	Include basin ID in legend	The legend has been modified to include the Basin ID
UDFCD - Morgan	19	Please provide a buffer around the delineation to confirm boundary, contours are hard to see	The extent of the contours has been buffered around the subwatershed boundaries
UDFCD - Morgan	19	The municipal boundaries are hard to see, would consider labeling them?	The symbology of the layer has been revised and labels were added to increase clarity of the exhibit
UDFCD - Morgan	19	Round to same significant digits for existing and future percent impervious	The basin labels have been revised
UDFCD - Morgan	19	Are there gaps in delineations for future land use?	There were areas in Commerce City that did not have a zoning designation. These areas were filled for the revised submittal
UDFCD - Morgan	19	Please eliminate gaps between basin delineations (multiple locations)	The apparent gaps in basin delinations were from the symbology of the basins overlapping the symbology of the jurisdictional boundaries. Symbology of both layers were revised to resolve the confusion
UDFCD - Morgan	19	Might be helpful to show the offsite basins with the same color as other exhibits and show the date. I would not expand the exhibit limits but let the basins extend beyond the page.	The existing study watersheds have been added to the interactive map
City of Denver	19	Please modify so that basin information symbols stay on when toggling the SWMM Routing Map on.	The interactive map link has been revised to leave the subwatershed label on.
City of Denver	19	Too low. I-70/I-270 is not 2% impervious.*	The team agreed to assign this area 50% future imperviousness to account for future developments around I-70 corridor

Draft Baseline Hydrology Comments (2)

Sponsor	PDF Report Page Number	Comment	ICON Response
Denver	6	Please expand to include area of each land use and also define by jurisdiction	The existing land use table has been revised to include the area of each land use
UDFCD - Morgan	6	Were there modifications to this data, if so, what were they? If not please state "no modifications."	No revisions were made to NLCD data for Commerce City. The report has been revised to reflect this.
UDFCD - Morgan	6	describe the percent of watershed currently developed.	
UDFCD - Morgan	7	This table might be clearer if there was some separation between jurisdictions with color or border?	Both the existing and future land use tables have been revised to include separation to increase clarity
Denver	8	If proceeding with a revision based on calibrating to the gage analysis, it may be worth including some statements that are supportive to the gage, data and results.	An additional section has been added on validation of model results
Denver	8	Include discussion of basis for determining peaks by shifting hydrographs. If there is any supporting information (figures, etc.) then include and reference.	Text has been added describing the delaying of hydrographs
Aurora	12	Please refer to the Original Aurora Study as the Original Aurora Stormwater Master Plan (throughout)	The report has been revised to refer to the study as the Original Aurora Stormwater Master Plan
UDFCD - Morgan	12	Should this area be identified on one of the maps?	The Original Aurora Stormwater Master Plan boundary has been added to the Study Area exhibit
UDFCD - Morgan	13	Please mention no detention in the unstudied area	Text has been added to state there was no detention in the unstudied area
Denver	13	Probably need to mention lagging of hydrogaphs as calibration here.	Text has been added about delaying the inflow hydrographs
UDFCD - Morgan	13	Pipe located where and what is the size?	The report was revised to include the size and location of the storm drain
UDFCD - Morgan	13	Any discussion on the Burlington Ditch?	Text was added to note the Burlington Ditch was assumed full during the hydrologic analysis
UDFCD - Morgan	13	It is interesting how much Type A soils are present in the 9 subbasins, probably a factor in the cfs/acre. Does this require some mention?	This comment was discussed with the district and determined no further analysis was needed.
UDFCD - Morgan	14	This paragraph seems a little out of place since no mention of calibration to this point. Maybe eliminate or mention based on the analysis and gage record, calibration was warranted	Report sections were reorganized to increase clarity
UDFCD - Morgan	14	This seems out of place. Should it move to the beginning of section 3 or at 3.5 and discuss what model was used and why?	Report sections were reorganized to increase clarity
UDFCD - Morgan	14	Provide context for the need for validation. Large basin, outside what is typical for the District	Text was added to the report adding context for the need for validation
UDFCD - Morgan	15	note in title if the flows are existing or future	A column was added to clarify the land use scenario
UDFCD - Morgan	15	Existing flows should be calibrated to an existing flow gage. Using that model add the future parameters for a future conditions model.	The results have been revised to calibrate to the existing conditions discharge
UDFCD - Morgan	15	In general I feel that the calibration process should precede the results discussion. Please provide narrative describing the initial results, why calibration was warranted and why it made sense to calibrate the way we did	Report sections were reorganized to increase clarity
UDFCD - Morgan	15	Suggest providing context as to why we had to calibrate and why timing was the correct factor, versus land use, percent impervious, etc.	The report was revised to include more information on the calibration approach
Denver	15	Include figure that documents modeling of existing conditions as appropriate.	Figures were added for the existing conditions analysis
UDFCD - Morgan	15	Provide documentation of that discussion and what led to that conclusion?	Documentation was added to the report text
UDFCD - Morgan	15	Include discussion of how calibration affected the existing conditions model results. And update as necessary to reflect results of any additional calibration efforts.	All tables and figures have been updated based on the calibration to the stream gage
UDFCD - Morgan	16	Please include a comparison for existing conditions	Figures were added for the existing conditions analysis
UDFCD - Morgan	17	This number does not calibrate well with the gage data	The table has been revised based on the calibration
UDFCD - Morgan	17	It appears there will be more than a 30 percent difference between existing and proposed, please provide a discussion on mapping existing flows.	Text has been added to the report describing the difference between existing and future is in excess of 30 percent

Draft Baseline Hydrology Comments (2)			
Sponsor	**PDF Report Page Number**	**Comment**	**ICON Response**
UDFCD - Morgan	18	Using existing flows for this figure	Figures were added for the existing conditions analysis
Denver	19	For this MDP/FHAD, there is a distinct possibility that flood hazards will need to be modeled/mapped the existing conditions hydrology. Please include figures like these that show the existing conditions hydrographs.	Figures were added for the existing conditions analysis
UDFCD / Denver	39	Misc. Comments on Interactive Map	The interactive map has been revised. An additional link has been added to allow toggling the subwatershed boundaries.

APPENDIX B - HYDROLOGIC ANALYSIS


Sand Creek Master Drainage Plan
Interactive Hydrology Map
Interactive Figures (Select from Below)
Study Area Map
Soils Map
Existing Land Use
Future Land Use
Baseline Hydrology SWMM Routing Map
2-, 10-ft Contours
On Off
Subwatershed Labels
On Off
Subbasin Label
SWMM Junction
SWMM Conduit
Subwatershed
Contour Major; 10-ft
Contour Minor; 2-ft
Jurisdictional Boundary
UDFCD Streams
Soil Type
A
B
C
D
Percent Impervious
Existing
1 - 10 %
11 - 20 %
21 - 30 %
31 - 40 %
41 - 50 %
51 - 60 %
61 - 70 %
71 - 80 %
81 - 90 %
91 - 100 %
Future
2 %
10 %
50 %
52 %
55 %
75 %
80 %
85 %
90 %
95 %
0 0.25 0.5 1 Mi
Commerce CITY
AURORA
DENVER THE MILE HIGH CITY
ICON ENGINEERING, INC.
City of Commerce City
City of Denver
City of Aurora
B010 0.718 61.5 94.0
B020 2.149 60.9 92.7
B030 3.636 43.6 72.7
B035 1.744 52.0 79.6
B040 1.698 51.4 80.7
B025 2.970 49.4 60.6
B050 1.490 41.2 54.4
B060 1.435 34.6 61.2
B070 0.992 24.3 52.5
Baranmoor Ditch
Sand Creek Right Bank Trib
Westerly Creek Lower
Toll Gate Creek East
Sand Creek - Colfax to Yale
Westerly Creek
Easterly Creek
Sable Ditch
Granby Ditch
Toll Gate Creek
Montbello Drainage
47th Ave Tributary
INTERSTATE 270
INTERSTATE 70
E 56TH AVE
E COLFAX AVE
High Line Canal

	Design Storm:	2-yr
	1-hr Point Rainfall (in):	0.86
	6-hr Point Rainfall (in):	1.36
	Correction Area (sq. mi.):	181
Design Storm Rainfall Distribution		
Time	Adjusted Depth	Unadjusted Depth
0:05	0.017	0.017
0:10	0.034	0.034
0:15	0.040	0.071
0:20	0.047	0.136
0:25	0.074	0.212
0:30	0.050	0.119
0:35	0.047	0.053
0:40	0.038	0.043
0:45	0.026	0.026
0:50	0.026	0.026
0:55	0.026	0.026
1:00	0.026	0.026
1:05	0.026	0.026
1:10	0.017	0.017
1:15	0.017	0.017
1:20	0.017	0.017
1:25	0.017	0.017
1:30	0.017	0.017
1:35	0.017	0.017
1:40	0.017	0.017
1:45	0.017	0.017
1:50	0.017	0.017
1:55	0.014	0.014
2:00	0.012	0.012
2:05	0.011	0.011
2:10	0.011	0.011
2:15	0.011	0.011
2:20	0.011	0.011
2:25	0.011	0.011
2:30	0.011	0.011
2:35	0.011	0.011
2:40	0.011	0.011
2:45	0.011	0.011
2:50	0.011	0.011
2:55	0.011	0.011
3:00	0.011	0.011
3:05	0.009	0.007
3:10	0.009	0.007
3:15	0.009	0.007
3:20	0.009	0.007
3:25	0.009	0.007
3:30	0.009	0.007
3:35	0.009	0.007
3:40	0.009	0.007
3:45	0.009	0.007
3:50	0.009	0.007
3:55	0.009	0.007
4:00	0.009	0.007
4:05	0.009	0.007
4:10	0.009	0.007
4:15	0.009	0.007
4:20	0.009	0.007
4:25	0.009	0.007
4:30	0.009	0.007
4:35	0.009	0.007
4:40	0.009	0.007
4:45	0.009	0.007
4:50	0.009	0.007
4:55	0.009	0.007
5:00	0.009	0.007
5:05	0.009	0.007
5:10	0.009	0.007
5:15	0.009	0.007
5:20	0.009	0.007
5:25	0.009	0.007
5:30	0.009	0.007
5:35	0.009	0.007
5:40	0.009	0.007
5:45	0.009	0.007
5:50	0.009	0.007
5:55	0.009	0.007
6:00	0.009	0.007

	Design Storm:	5-yr
	1-hr Point Rainfall (in):	1.14
	6-hr Point Rainfall (in):	1.77
	Correction Area (sq. mi.):	181
Design Storm Rainfall Distribution		
Time	Adjusted Depth	Unadjusted Depth
0:05	0.023	0.023
0:10	0.042	0.042
0:15	0.056	0.099
0:20	0.061	0.174
0:25	0.100	0.285
0:30	0.062	0.148
0:35	0.059	0.066
0:40	0.045	0.050
0:45	0.041	0.041
0:50	0.041	0.041
0:55	0.034	0.034
1:00	0.034	0.034
1:05	0.034	0.034
1:10	0.034	0.034
1:15	0.029	0.029
1:20	0.025	0.025
1:25	0.025	0.025
1:30	0.025	0.025
1:35	0.025	0.025
1:40	0.017	0.017
1:45	0.017	0.017
1:50	0.017	0.017
1:55	0.017	0.017
2:00	0.015	0.015
2:05	0.013	0.013
2:10	0.013	0.013
2:15	0.013	0.013
2:20	0.013	0.013
2:25	0.013	0.013
2:30	0.013	0.013
2:35	0.013	0.013
2:40	0.013	0.013
2:45	0.013	0.013
2:50	0.013	0.013
2:55	0.013	0.013
3:00	0.013	0.013
3:05	0.011	0.008
3:10	0.011	0.008
3:15	0.011	0.008
3:20	0.011	0.008
3:25	0.011	0.008
3:30	0.011	0.008
3:35	0.011	0.008
3:40	0.011	0.008
3:45	0.011	0.008
3:50	0.011	0.008
3:55	0.011	0.008
4:00	0.011	0.008
4:05	0.011	0.008
4:10	0.011	0.008
4:15	0.011	0.008
4:20	0.011	0.008
4:25	0.011	0.008
4:30	0.011	0.008
4:35	0.011	0.008
4:40	0.011	0.008
4:45	0.011	0.008
4:50	0.011	0.008
4:55	0.011	0.008
5:00	0.011	0.008
5:05	0.011	0.008
5:10	0.011	0.008
5:15	0.011	0.008
5:20	0.011	0.008
5:25	0.011	0.008
5:30	0.011	0.008
5:35	0.011	0.008
5:40	0.011	0.008
5:45	0.011	0.008
5:50	0.011	0.008
5:55	0.011	0.008
6:00	0.011	0.008

	Design Storm:	10-yr
	1-hr Point Rainfall (in):	1.4
	6-hr Point Rainfall (in):	2.14
	Correction Area (sq. mi.):	181
Design Storm Rainfall Distribution		
Time	Adjusted Depth	Unadjusted Depth
0:05	0.028	0.028
0:10	0.052	0.052
0:15	0.064	0.115
0:20	0.074	0.210
0:25	0.122	0.350
0:30	0.071	0.168
0:35	0.070	0.078
0:40	0.054	0.060
0:45	0.053	0.053
0:50	0.045	0.045
0:55	0.045	0.045
1:00	0.045	0.045
1:05	0.045	0.045
1:10	0.045	0.045
1:15	0.045	0.045
1:20	0.035	0.035
1:25	0.027	0.027
1:30	0.027	0.027
1:35	0.027	0.027
1:40	0.027	0.027
1:45	0.027	0.027
1:50	0.027	0.027
1:55	0.024	0.024
2:00	0.018	0.018
2:05	0.016	0.016
2:10	0.016	0.016
2:15	0.016	0.016
2:20	0.016	0.016
2:25	0.016	0.016
2:30	0.016	0.016
2:35	0.016	0.016
2:40	0.016	0.016
2:45	0.016	0.016
2:50	0.016	0.016
2:55	0.016	0.016
3:00	0.016	0.016
3:05	0.012	0.009
3:10	0.012	0.009
3:15	0.012	0.009
3:20	0.012	0.009
3:25	0.012	0.009
3:30	0.012	0.009
3:35	0.012	0.009
3:40	0.012	0.009
3:45	0.012	0.009
3:50	0.012	0.009
3:55	0.012	0.009
4:00	0.012	0.009
4:05	0.012	0.009
4:10	0.012	0.009
4:15	0.012	0.009
4:20	0.012	0.009
4:25	0.012	0.009
4:30	0.012	0.009
4:35	0.012	0.009
4:40	0.012	0.009
4:45	0.012	0.009
4:50	0.012	0.009
4:55	0.012	0.009
5:00	0.012	0.009
5:05	0.012	0.009
5:10	0.012	0.009
5:15	0.012	0.009
5:20	0.012	0.009
5:25	0.012	0.009
5:30	0.012	0.009
5:35	0.012	0.009
5:40	0.012	0.009
5:45	0.012	0.009
5:50	0.012	0.009
5:55	0.012	0.009
6:00	0.012	0.009

	Design Storm:	25-yr
	1-hr Point Rainfall (in):	1.78
	6-hr Point Rainfall (in):	2.7
	Correction Area (sq. mi.):	181
Design Storm Rainfall Distribution		
Time	Adjusted Depth	Unadjusted Depth
0:05	0.025	0.023
0:10	0.069	0.062
0:15	0.098	0.089
0:20	0.128	0.142
0:25	0.147	0.267
0:30	0.245	0.445
0:35	0.117	0.214
0:40	0.114	0.142
0:45	0.085	0.089
0:50	0.085	0.089
0:55	0.066	0.057
1:00	0.066	0.057
1:05	0.066	0.057
1:10	0.049	0.043
1:15	0.049	0.043
1:20	0.037	0.032
1:25	0.037	0.032
1:30	0.029	0.025
1:35	0.029	0.025
1:40	0.029	0.025
1:45	0.029	0.025
1:50	0.029	0.025
1:55	0.029	0.025
2:00	0.029	0.025
2:05	0.024	0.020
2:10	0.024	0.020
2:15	0.024	0.020
2:20	0.024	0.020
2:25	0.024	0.020
2:30	0.024	0.020
2:35	0.024	0.020
2:40	0.024	0.020
2:45	0.024	0.020
2:50	0.024	0.020
2:55	0.024	0.020
3:00	0.024	0.020
3:05	0.013	0.011
3:10	0.013	0.011
3:15	0.013	0.011
3:20	0.013	0.011
3:25	0.013	0.011
3:30	0.013	0.011
3:35	0.013	0.011
3:40	0.013	0.011
3:45	0.013	0.011
3:50	0.013	0.011
3:55	0.013	0.011
4:00	0.013	0.011
4:05	0.013	0.011
4:10	0.013	0.011
4:15	0.013	0.011
4:20	0.013	0.011
4:25	0.013	0.011
4:30	0.013	0.011
4:35	0.013	0.011
4:40	0.013	0.011
4:45	0.013	0.011
4:50	0.013	0.011
4:55	0.013	0.011
5:00	0.013	0.011
5:05	0.013	0.011
5:10	0.013	0.011
5:15	0.013	0.011
5:20	0.013	0.011
5:25	0.013	0.011
5:30	0.013	0.011
5:35	0.013	0.011
5:40	0.013	0.011
5:45	0.013	0.011
5:50	0.013	0.011
5:55	0.013	0.011
6:00	0.013	0.011

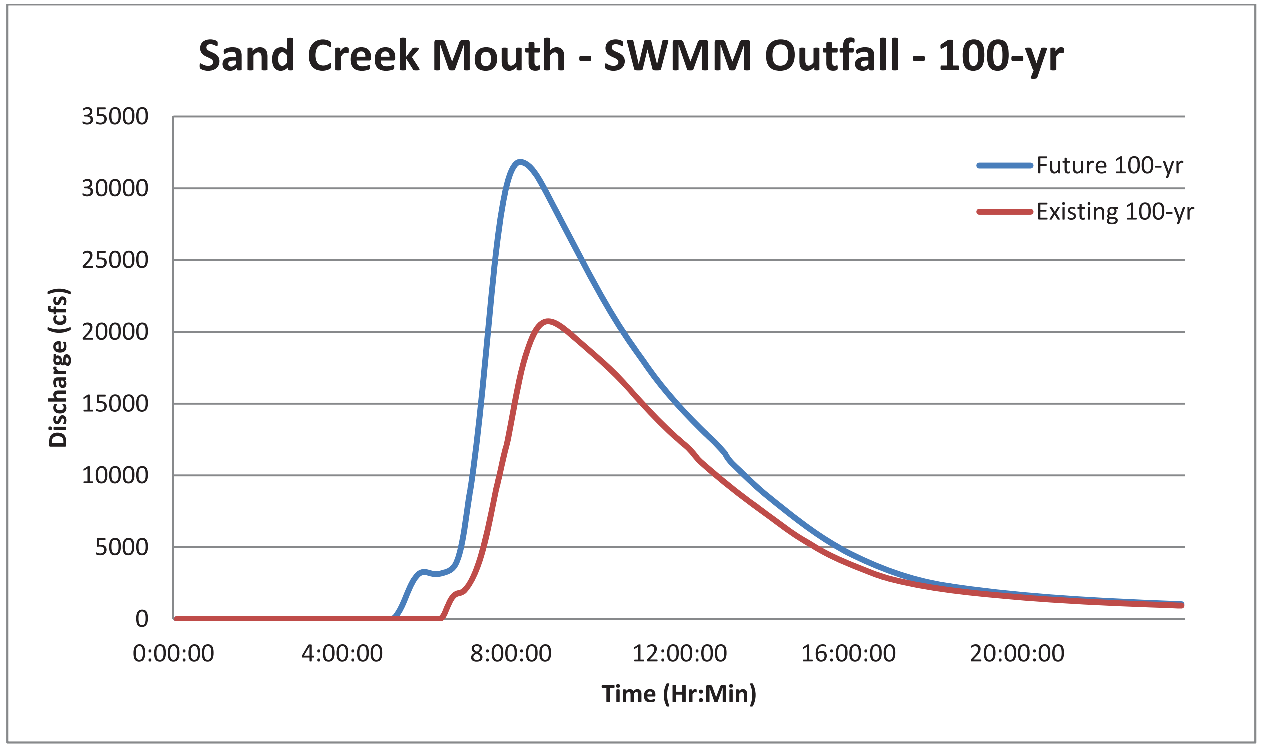
	Design Storm:	50-yr
	1-hr Point Rainfall (in):	2.1
	6-hr Point Rainfall (in):	3.18
	Correction Area (sq. mi.):	181
Design Storm Rainfall Distribution		
Time	Adjusted Depth	Unadjusted Depth
0:05	0.030	0.027
0:10	0.081	0.073
0:15	0.115	0.105
0:20	0.151	0.168
0:25	0.173	0.315
0:30	0.289	0.525
0:35	0.139	0.252
0:40	0.134	0.168
0:45	0.100	0.105
0:50	0.100	0.105
0:55	0.077	0.067
1:00	0.077	0.067
1:05	0.077	0.067
1:10	0.058	0.050
1:15	0.058	0.050
1:20	0.043	0.038
1:25	0.043	0.038
1:30	0.034	0.029
1:35	0.034	0.029
1:40	0.034	0.029
1:45	0.034	0.029
1:50	0.034	0.029
1:55	0.034	0.029
2:00	0.034	0.029
2:05	0.029	0.023
2:10	0.029	0.023
2:15	0.029	0.023
2:20	0.029	0.023
2:25	0.029	0.023
2:30	0.029	0.023
2:35	0.029	0.023
2:40	0.029	0.023
2:45	0.029	0.023
2:50	0.029	0.023
2:55	0.029	0.023
3:00	0.029	0.023
3:05	0.015	0.013
3:10	0.015	0.013
3:15	0.015	0.013
3:20	0.015	0.013
3:25	0.015	0.013
3:30	0.015	0.013
3:35	0.015	0.013
3:40	0.015	0.013
3:45	0.015	0.013
3:50	0.015	0.013
3:55	0.015	0.013
4:00	0.015	0.013
4:05	0.015	0.013
4:10	0.015	0.013
4:15	0.015	0.013
4:20	0.015	0.013
4:25	0.015	0.013
4:30	0.015	0.013
4:35	0.015	0.013
4:40	0.015	0.013
4:45	0.015	0.013
4:50	0.015	0.013
4:55	0.015	0.013
5:00	0.015	0.013
5:05	0.015	0.013
5:10	0.015	0.013
5:15	0.015	0.013
5:20	0.015	0.013
5:25	0.015	0.013
5:30	0.015	0.013
5:35	0.015	0.013
5:40	0.015	0.013
5:45	0.015	0.013
5:50	0.015	0.013
5:55	0.015	0.013
6:00	0.015	0.013

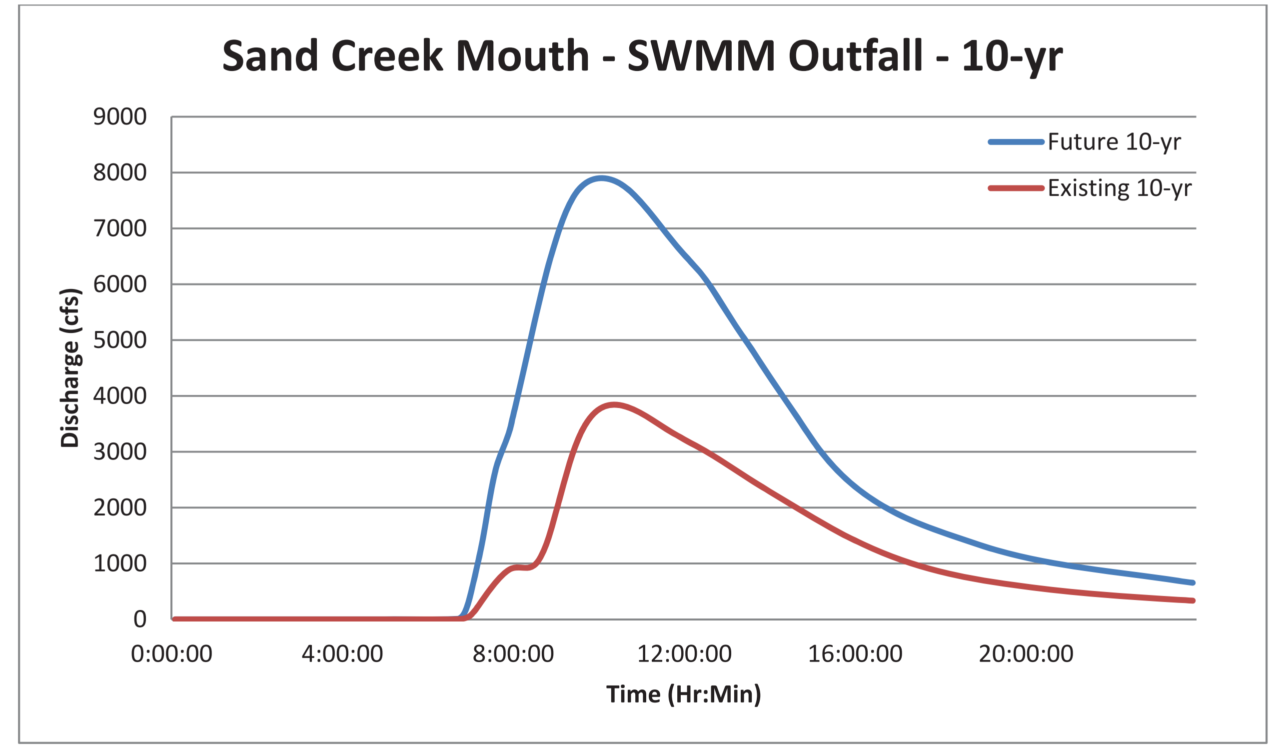
	Design Storm:	100-yr
	1-hr Point Rainfall (in):	2.44
	6-hr Point Rainfall (in):	3.69
	Correction Area (sq. mi.):	181
Design Storm Rainfall Distribution		
Time	Adjusted Depth	Unadjusted Depth
0:05	0.027	0.024
0:10	0.081	0.073
0:15	0.123	0.112
0:20	0.176	0.195
0:25	0.188	0.342
0:30	0.336	0.610
0:35	0.188	0.342
0:40	0.156	0.195
0:45	0.144	0.151
0:50	0.116	0.122
0:55	0.112	0.098
1:00	0.112	0.098
1:05	0.112	0.098
1:10	0.056	0.049
1:15	0.056	0.049
1:20	0.034	0.029
1:25	0.034	0.029
1:30	0.034	0.029
1:35	0.034	0.029
1:40	0.034	0.029
1:45	0.034	0.029
1:50	0.034	0.029
1:55	0.034	0.029
2:00	0.034	0.029
2:05	0.033	0.027
2:10	0.033	0.027
2:15	0.033	0.027
2:20	0.033	0.027
2:25	0.033	0.027
2:30	0.033	0.027
2:35	0.033	0.027
2:40	0.033	0.027
2:45	0.033	0.027
2:50	0.033	0.027
2:55	0.033	0.027
3:00	0.033	0.027
3:05	0.017	0.015
3:10	0.017	0.015
3:15	0.017	0.015
3:20	0.017	0.015
3:25	0.017	0.015
3:30	0.017	0.015
3:35	0.017	0.015
3:40	0.017	0.015
3:45	0.017	0.015
3:50	0.017	0.015
3:55	0.017	0.015
4:00	0.017	0.015
4:05	0.017	0.015
4:10	0.017	0.015
4:15	0.017	0.015
4:20	0.017	0.015
4:25	0.017	0.015
4:30	0.017	0.015
4:35	0.017	0.015
4:40	0.017	0.015
4:45	0.017	0.015
4:50	0.017	0.015
4:55	0.017	0.015
5:00	0.017	0.015
5:05	0.017	0.015
5:10	0.017	0.015
5:15	0.017	0.015
5:20	0.017	0.015
5:25	0.017	0.015
5:30	0.017	0.015
5:35	0.017	0.015
5:40	0.017	0.015
5:45	0.017	0.015
5:50	0.017	0.015
5:55	0.017	0.015
6:00	0.017	0.015

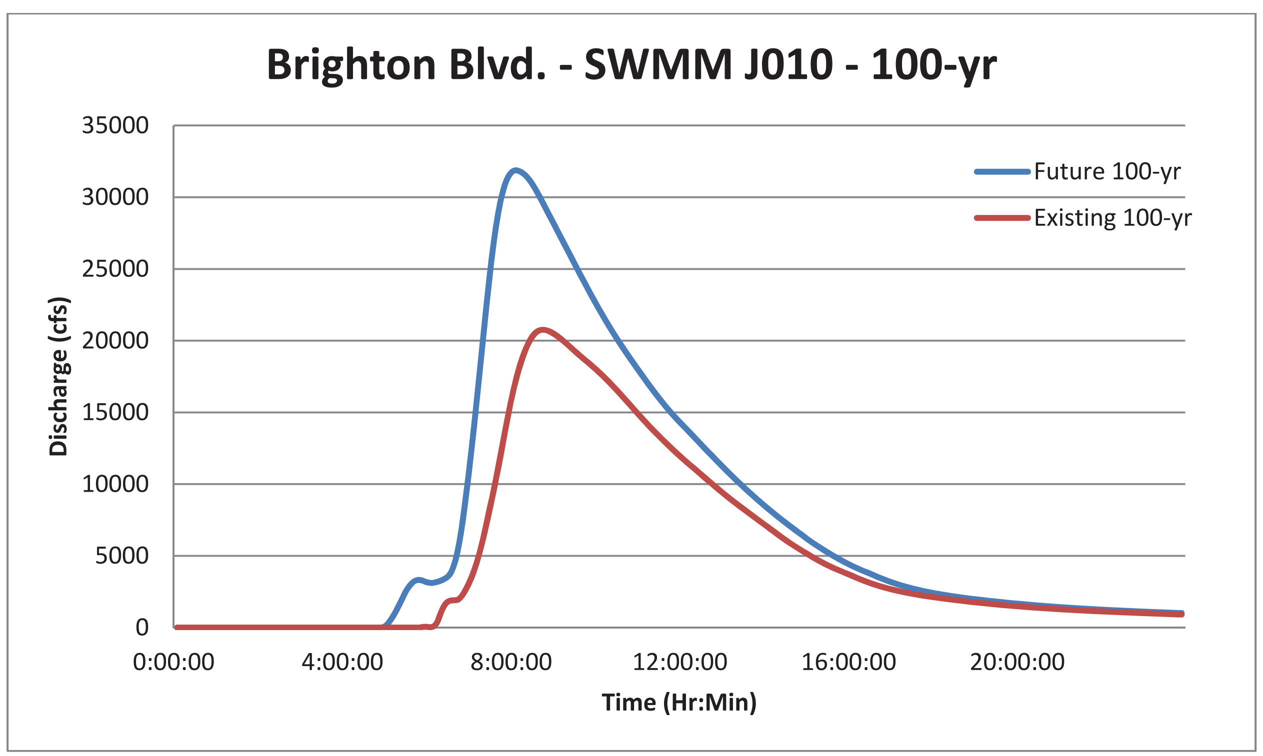
	Design Storm:	500-yr
	1-hr Point Rainfall (in):	3.33
	6-hr Point Rainfall (in):	5.03
	Correction Area (sq. mi.):	181
Design Storm Rainfall Distribution		
Time	Adjusted Depth	Unadjusted Depth
0:05	0.037	0.033
0:10	0.110	0.100
0:15	0.168	0.153
0:20	0.240	0.266
0:25	0.256	0.466
0:30	0.458	0.832
0:35	0.256	0.466
0:40	0.213	0.266
0:45	0.196	0.206
0:50	0.158	0.166
0:55	0.153	0.133
1:00	0.153	0.133
1:05	0.153	0.133
1:10	0.077	0.067
1:15	0.077	0.067
1:20	0.046	0.040
1:25	0.046	0.040
1:30	0.046	0.040
1:35	0.046	0.040
1:40	0.046	0.040
1:45	0.046	0.040
1:50	0.046	0.040
1:55	0.046	0.040
2:00	0.046	0.040
2:05	0.045	0.036
2:10	0.045	0.036
2:15	0.045	0.036
2:20	0.045	0.036
2:25	0.045	0.036
2:30	0.045	0.036
2:35	0.045	0.036
2:40	0.045	0.036
2:45	0.045	0.036
2:50	0.045	0.036
2:55	0.045	0.036
3:00	0.045	0.036
3:05	0.023	0.021
3:10	0.023	0.021
3:15	0.023	0.021
3:20	0.023	0.021
3:25	0.023	0.021
3:30	0.023	0.021
3:35	0.023	0.021
3:40	0.023	0.021
3:45	0.023	0.021
3:50	0.023	0.021
3:55	0.023	0.021
4:00	0.023	0.021
4:05	0.023	0.021
4:10	0.023	0.021
4:15	0.023	0.021
4:20	0.023	0.021
4:25	0.023	0.021
4:30	0.023	0.021
4:35	0.023	0.021
4:40	0.023	0.021
4:45	0.023	0.021
4:50	0.023	0.021
4:55	0.023	0.021
5:00	0.023	0.021
5:05	0.023	0.021
5:10	0.023	0.021
5:15	0.023	0.021
5:20	0.023	0.021
5:25	0.023	0.021
5:30	0.023	0.021
5:35	0.023	0.021
5:40	0.023	0.021
5:45	0.023	0.021
5:50	0.023	0.021
5:55	0.023	0.021
6:00	0.023	0.021

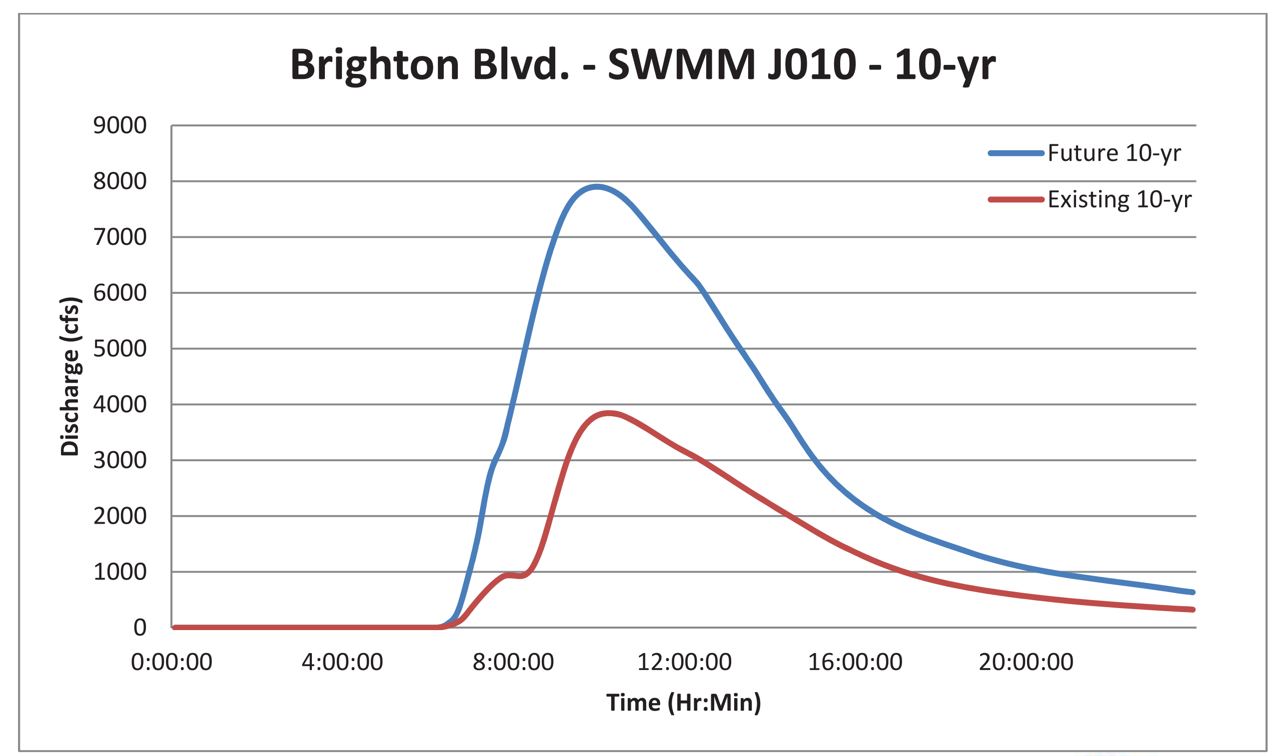
CUHP Input Parameters													
Subcatchment Name	EPA SWMM Target Node	Raingage	Area (mi^2)	Length to Centroid (mi)	Length (mi)	Slope (ft/ft)	Existing Percent Imperviousness	Future Percent Imperviousness	Pervious	Impervious	Initial Rate (in/hr)	Decay Coefficient (1/seconds)	Final Rate (in/hr)
B010	B010	Sand_Creek	0.7181	1.0594	1.6642	0.0061	61.5	94.0	0.35	0.1	4.99	0.0007	1
B020	B020	Sand_Creek	2.1491	1.0848	2.4671	0.0084	60.9	92.7	0.35	0.1	4.37	0.0012	0.78
B025	B025	Sand_Creek	2.9701	1.9409	3.8870	0.0064	49.4	60.6	0.35	0.1	3.5	0.0018	0.5
B030	B030	Sand_Creek	3.6360	1.4064	3.7038	0.0039	43.6	72.7	0.35	0.1	5	0.0007	1
B035	B035	Sand_Creek	1.7436	1.4666	2.7337	0.0058	52.0	79.6	0.35	0.1	4.06	0.0018	0.56
B040	B040	Sand_Creek	1.6981	1.8145	3.2306	0.0058	51.4	80.7	0.35	0.1	3.98	0.0015	0.65
B050	B050	Sand_Creek	1.4904	1.5476	3.0544	0.0095	41.2	54.4	0.35	0.1	3.56	0.0018	0.51
B060	B060	Sand_Creek	1.4348	1.6692	3.2523	0.0099	34.6	61.2	0.35	0.1	3.91	0.0016	0.59
B070	B070	Sand_Creek	0.9918	2.0100	3.8561	0.0067	24.3	52.5	0.35	0.1	4.77	0.0011	0.85

10- and 100-year Hydrographs

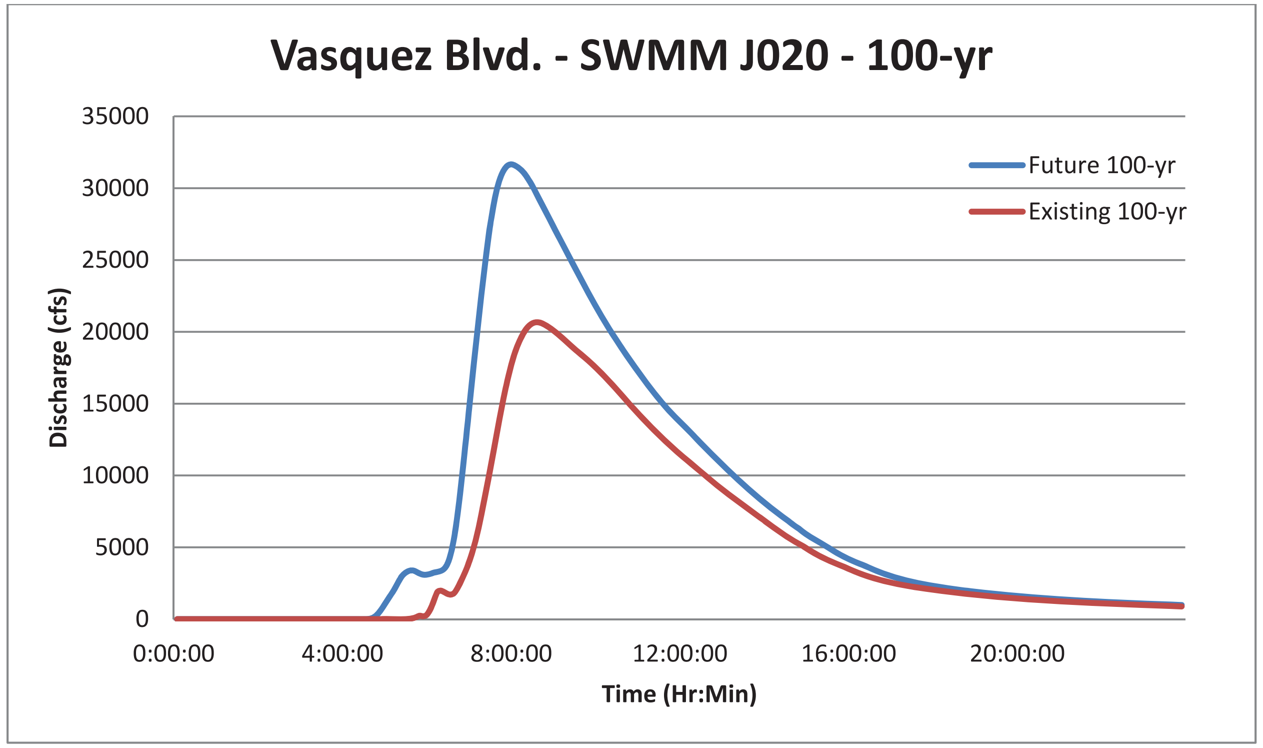


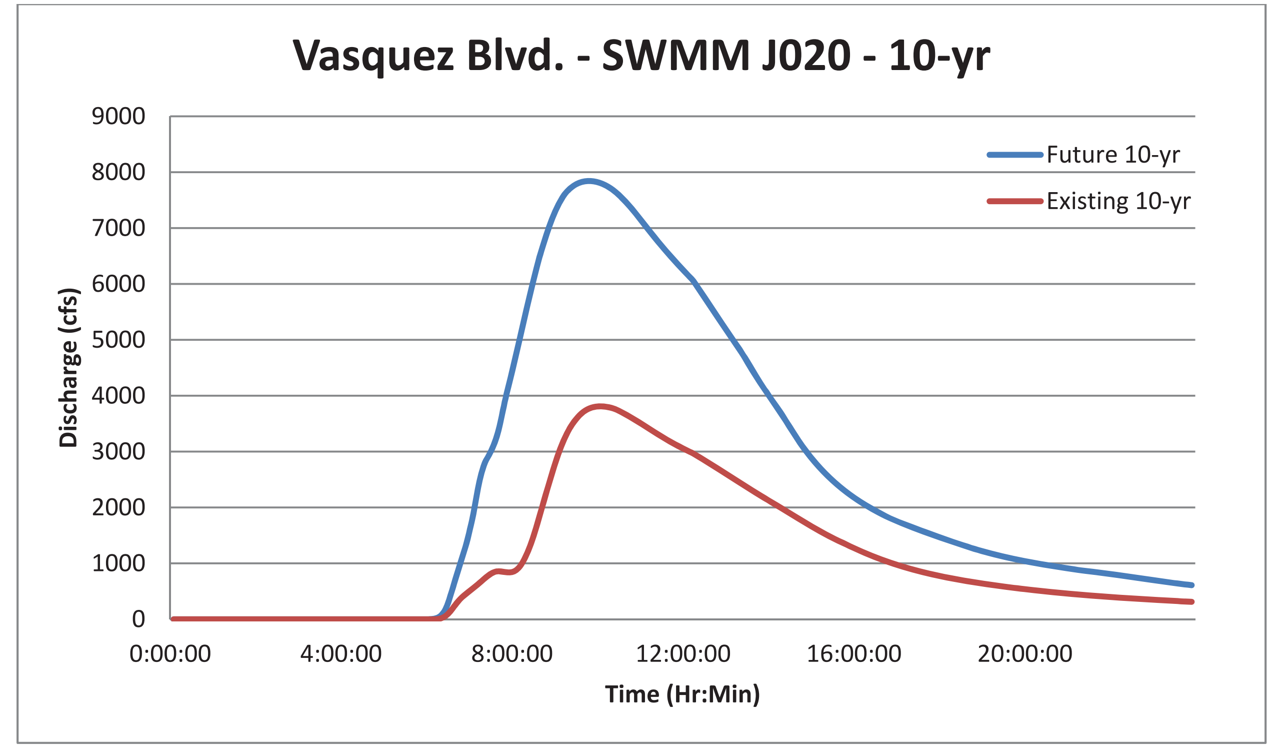


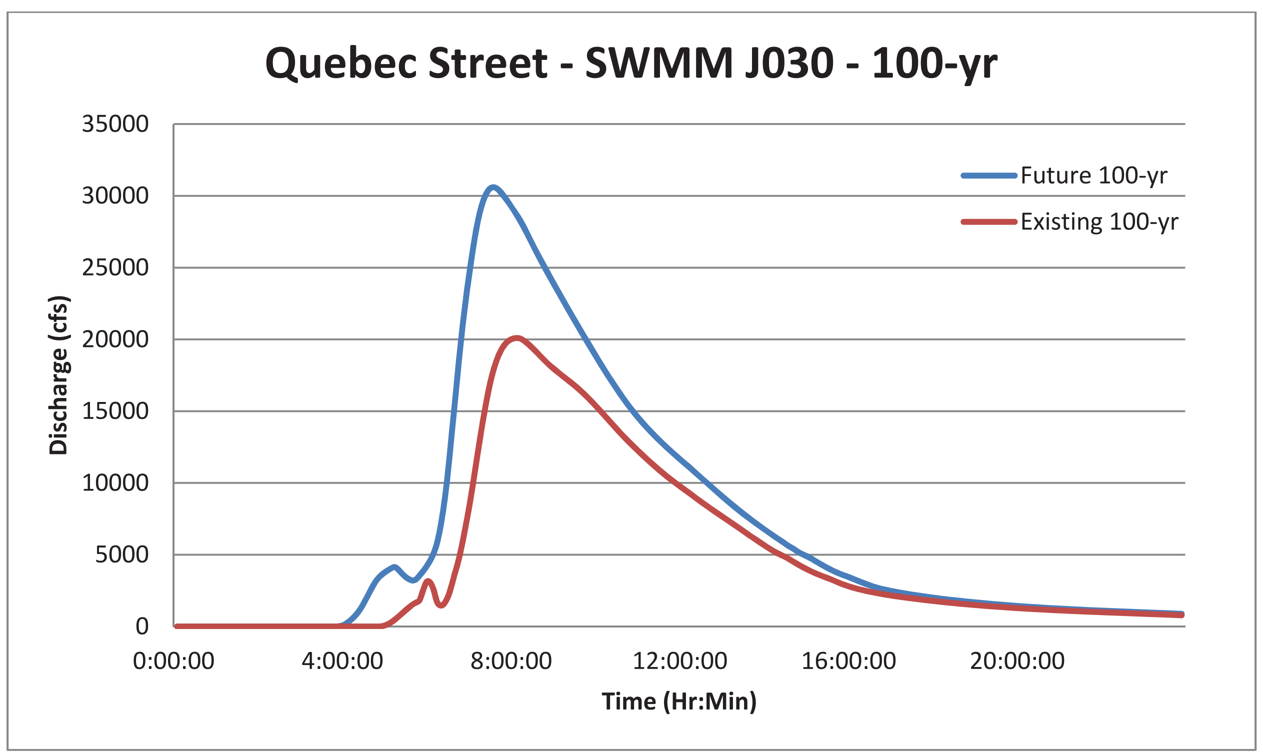


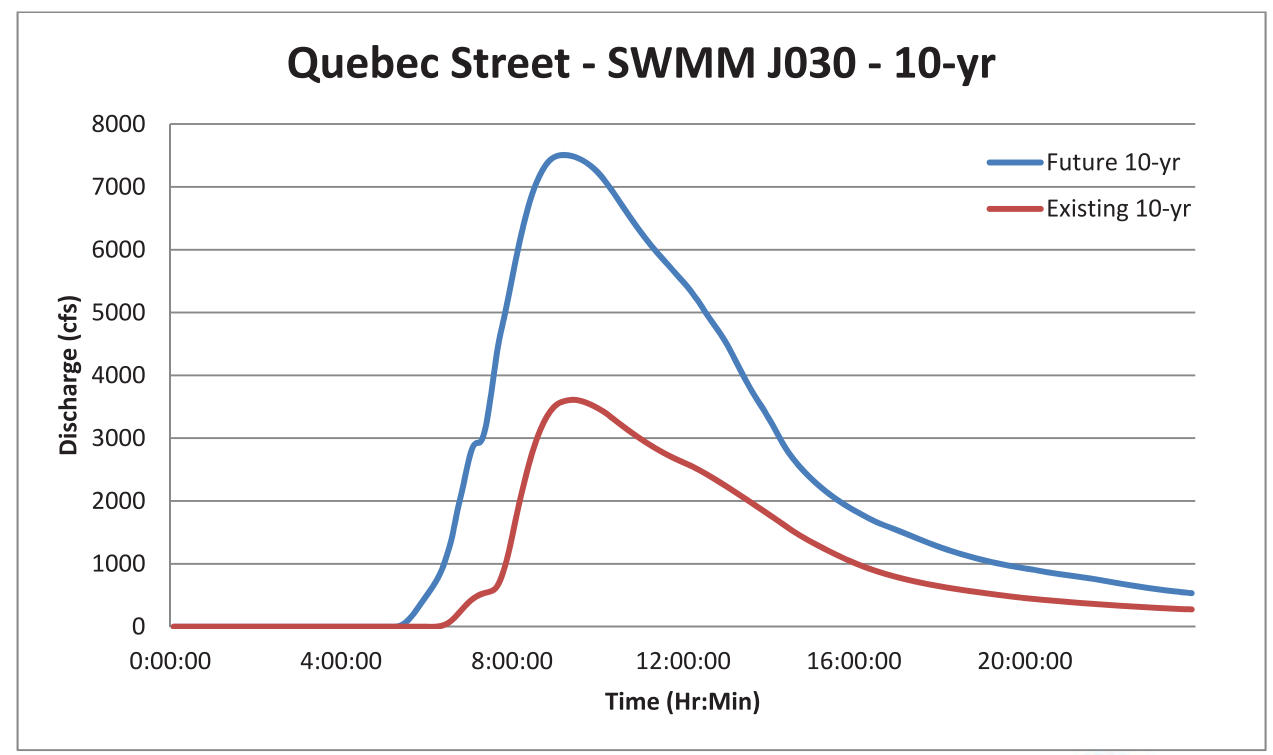


10- and 100-year Hydrographs









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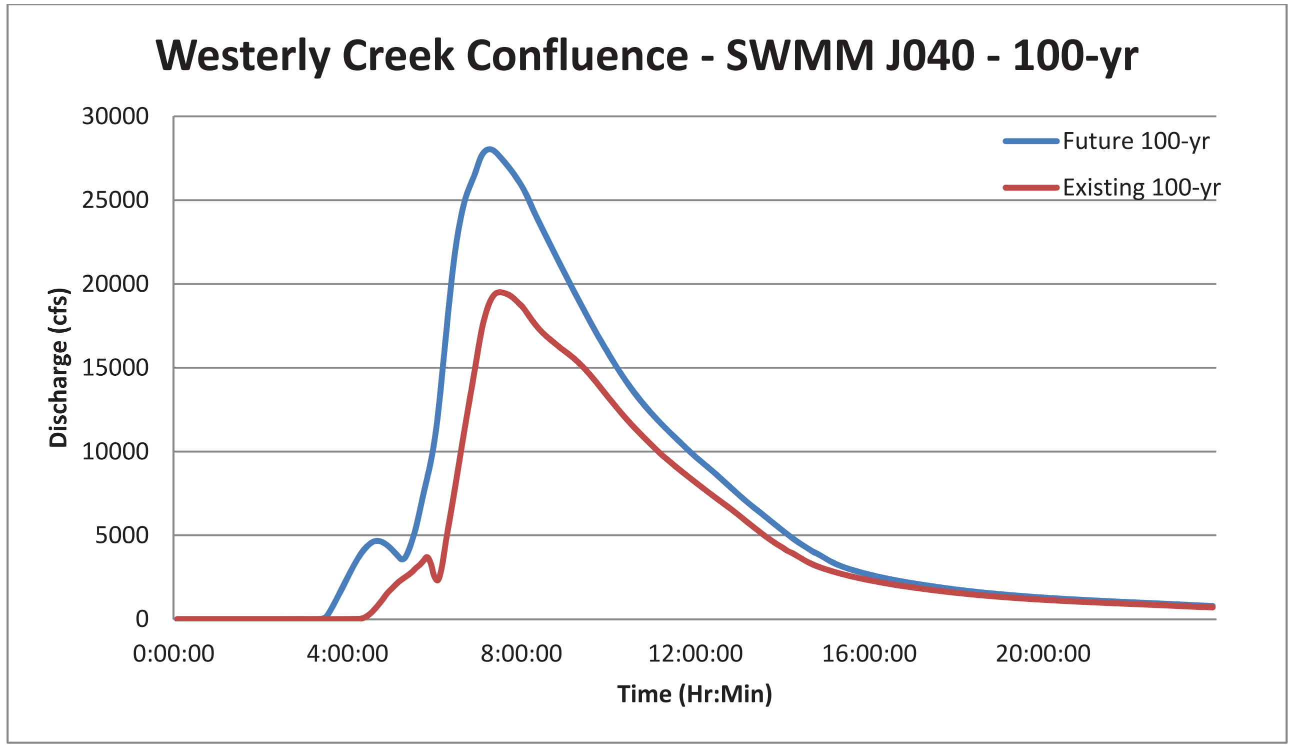
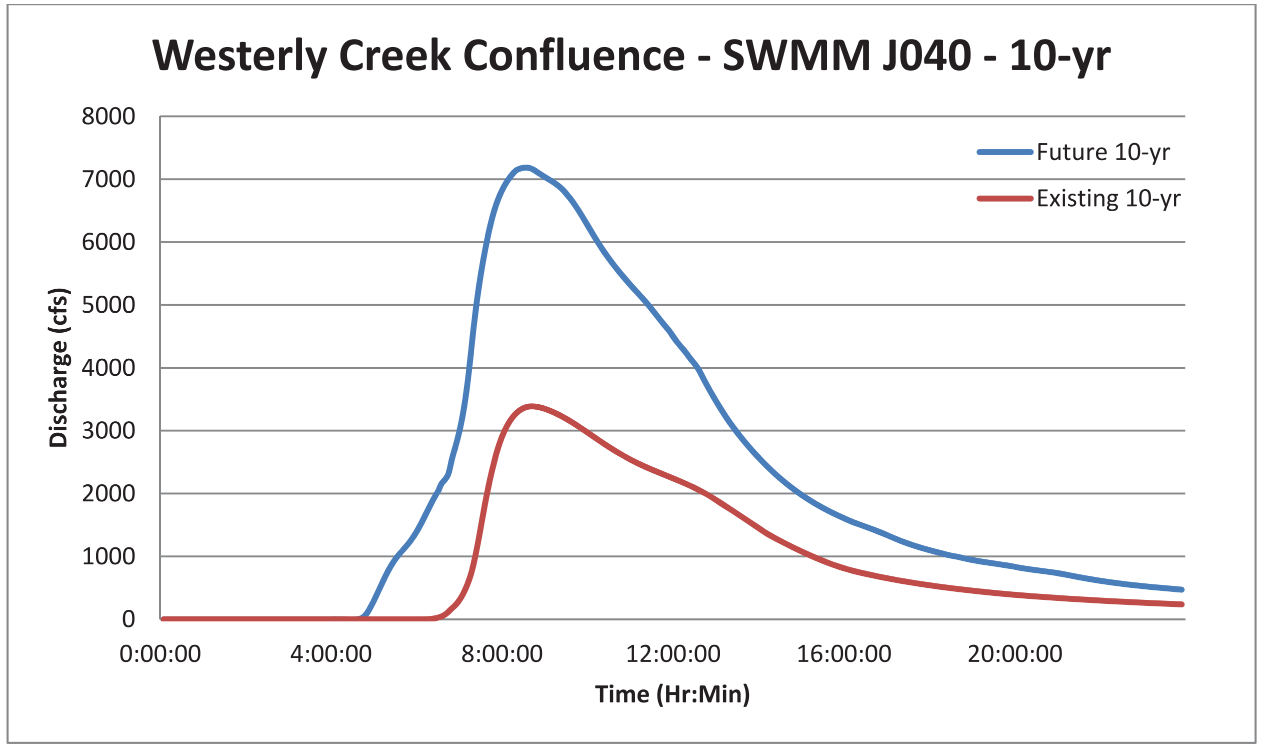
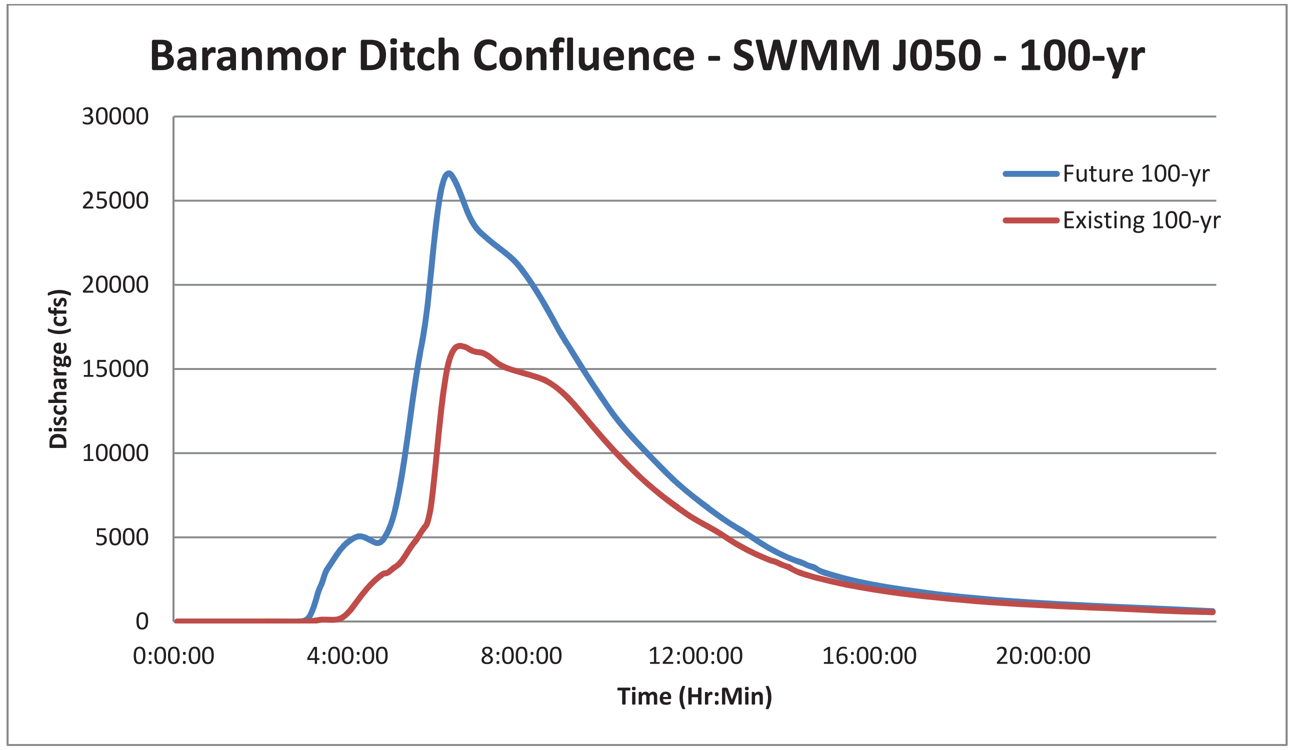
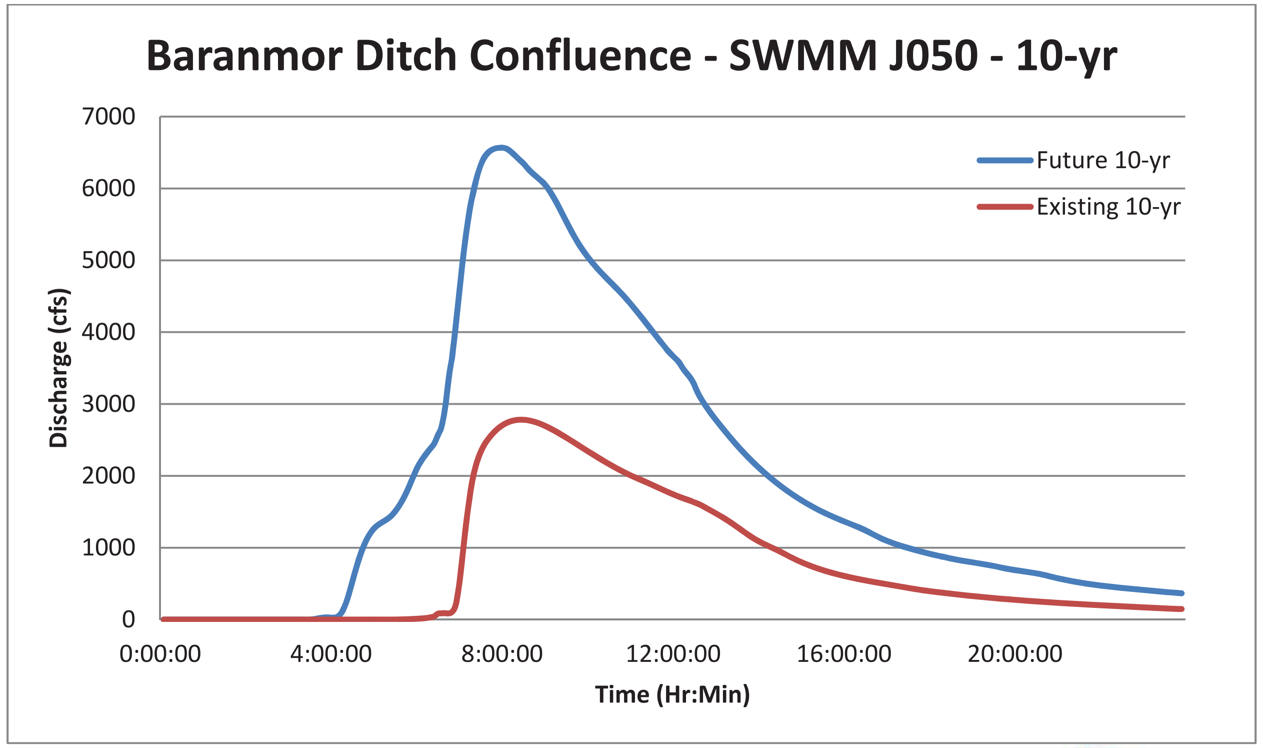
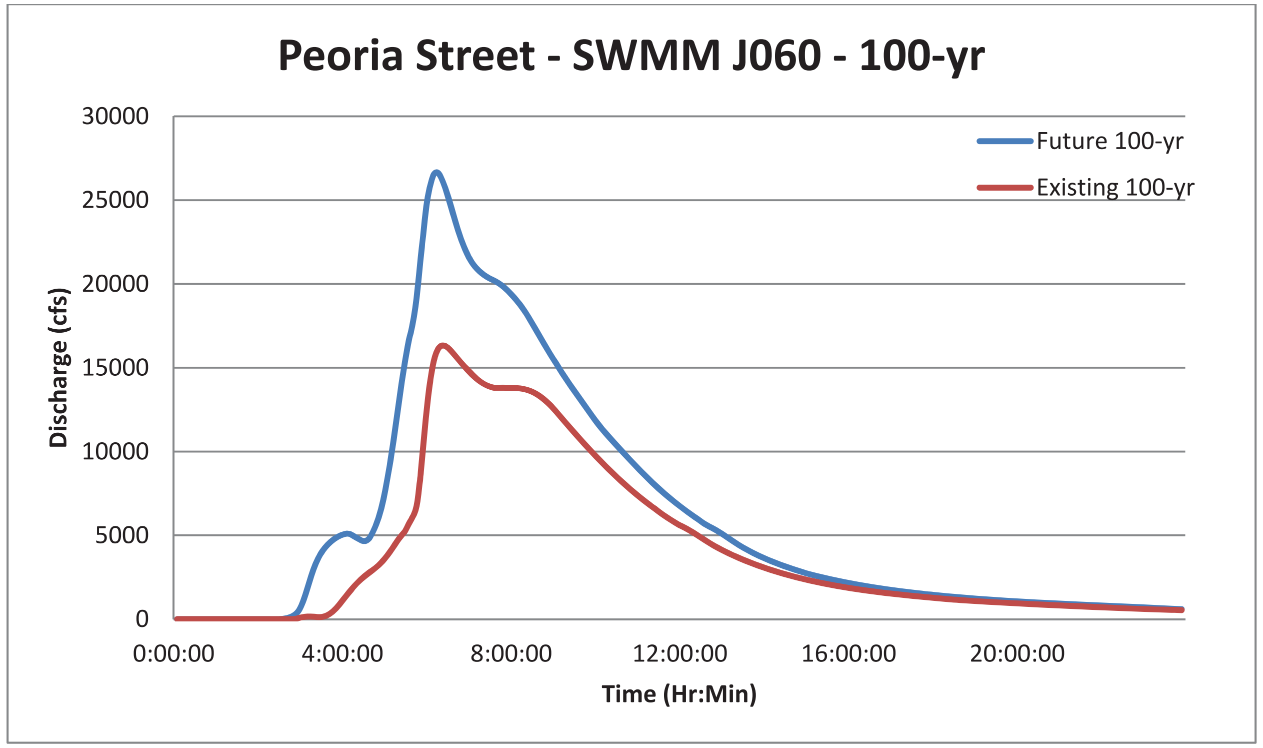


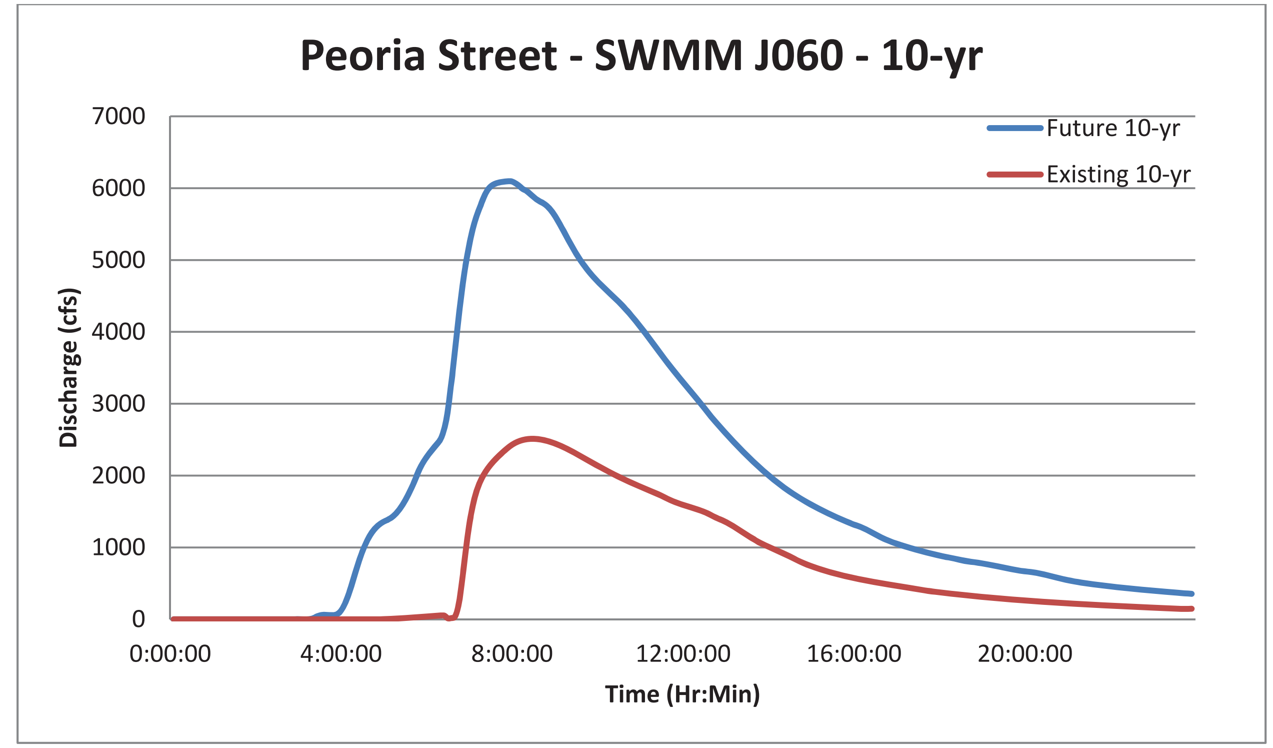


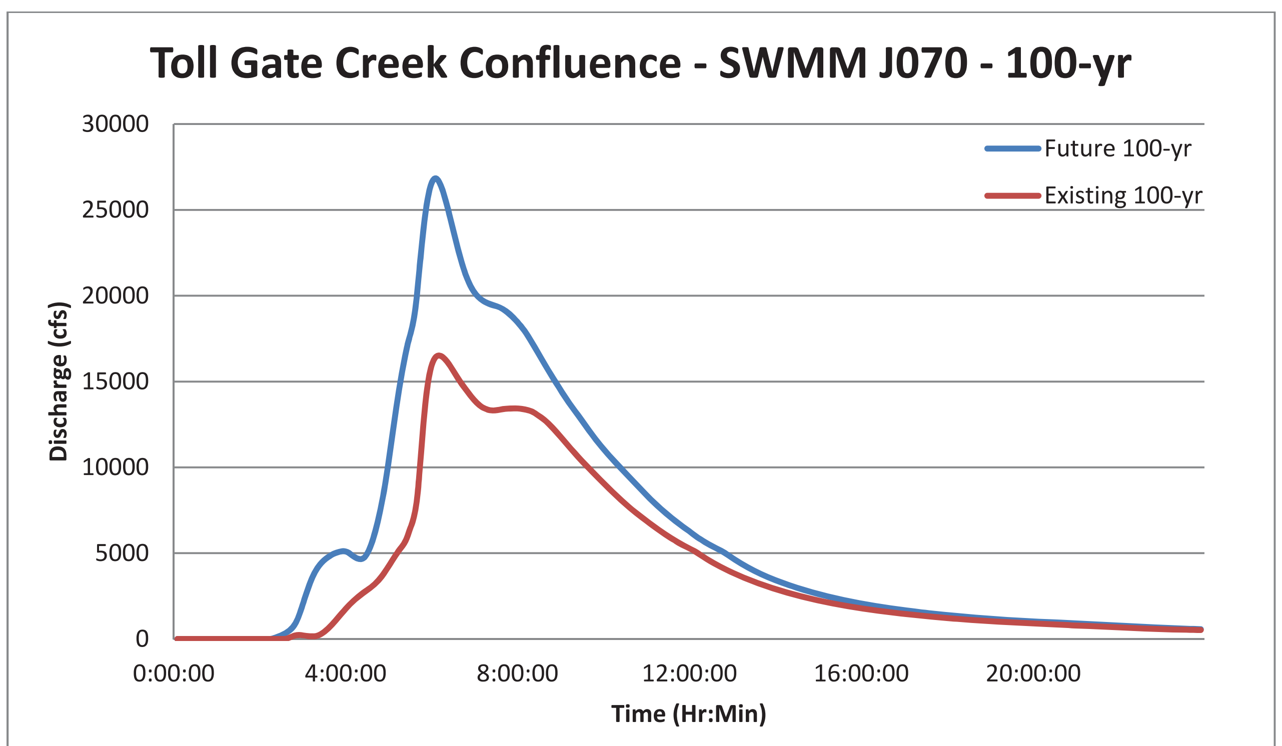


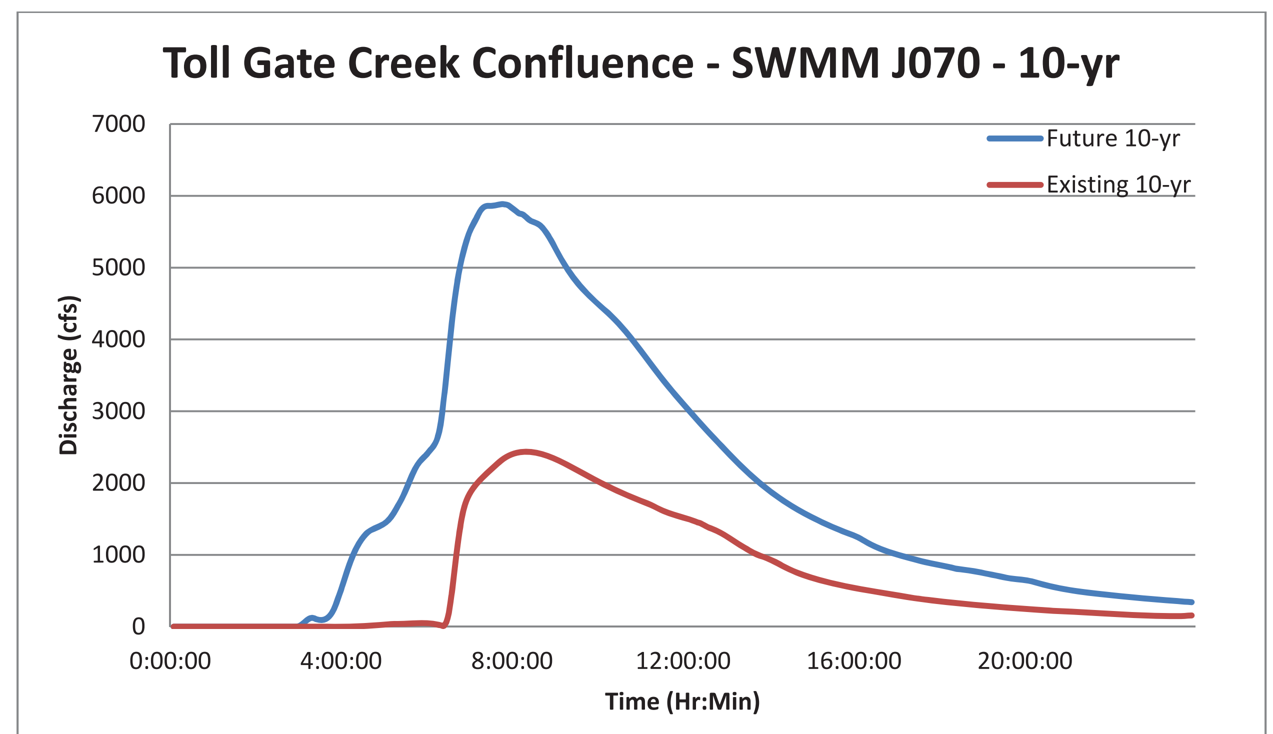


10- and 100-year Hydrographs









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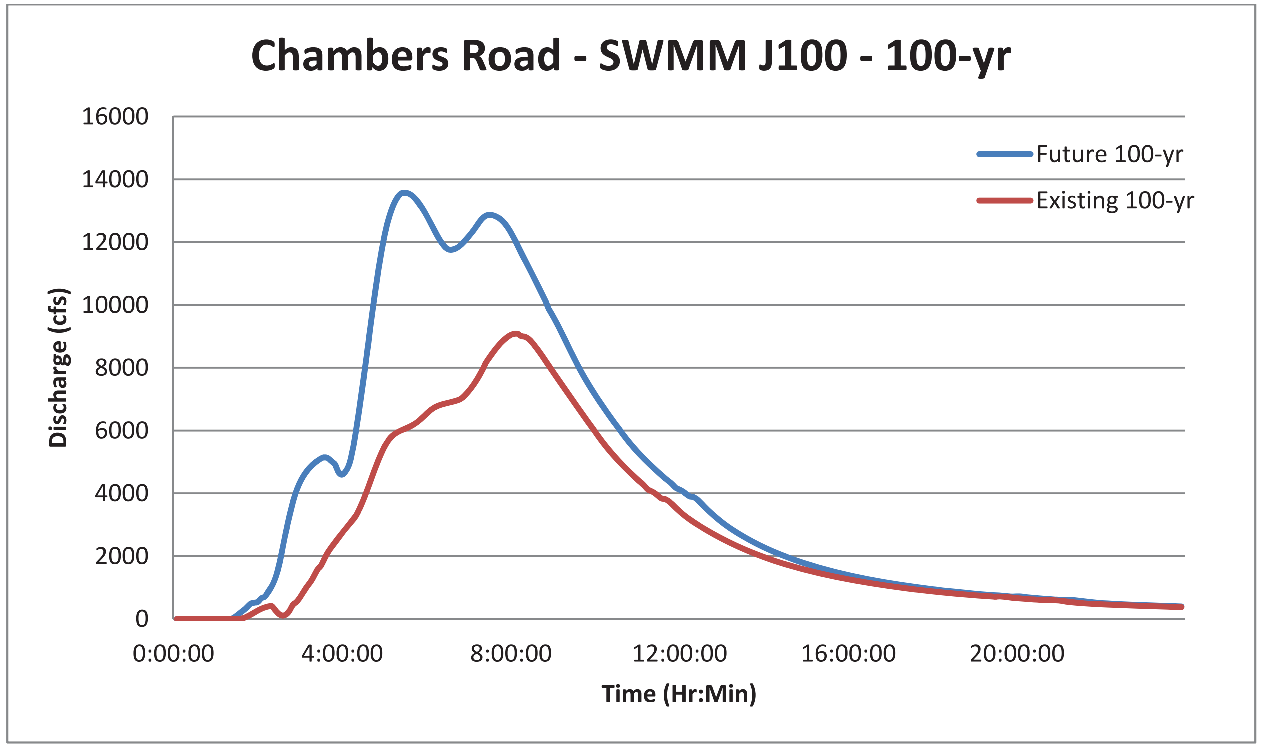
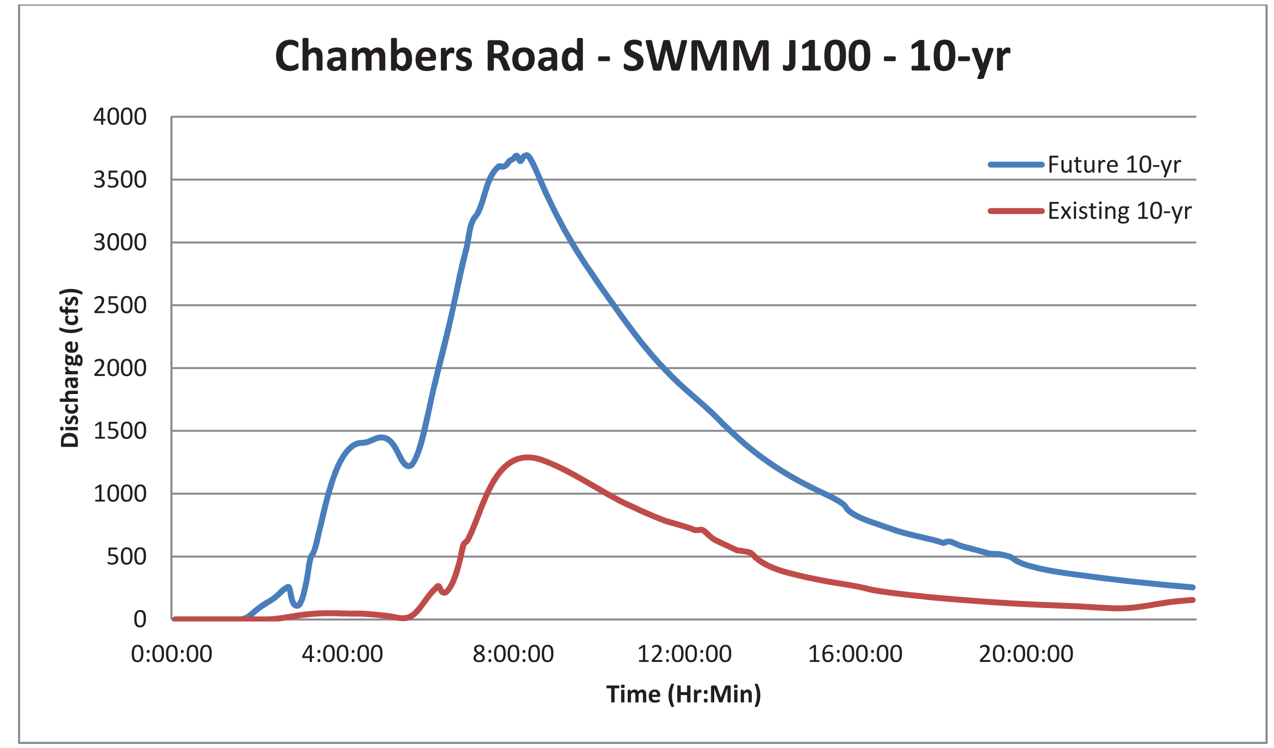
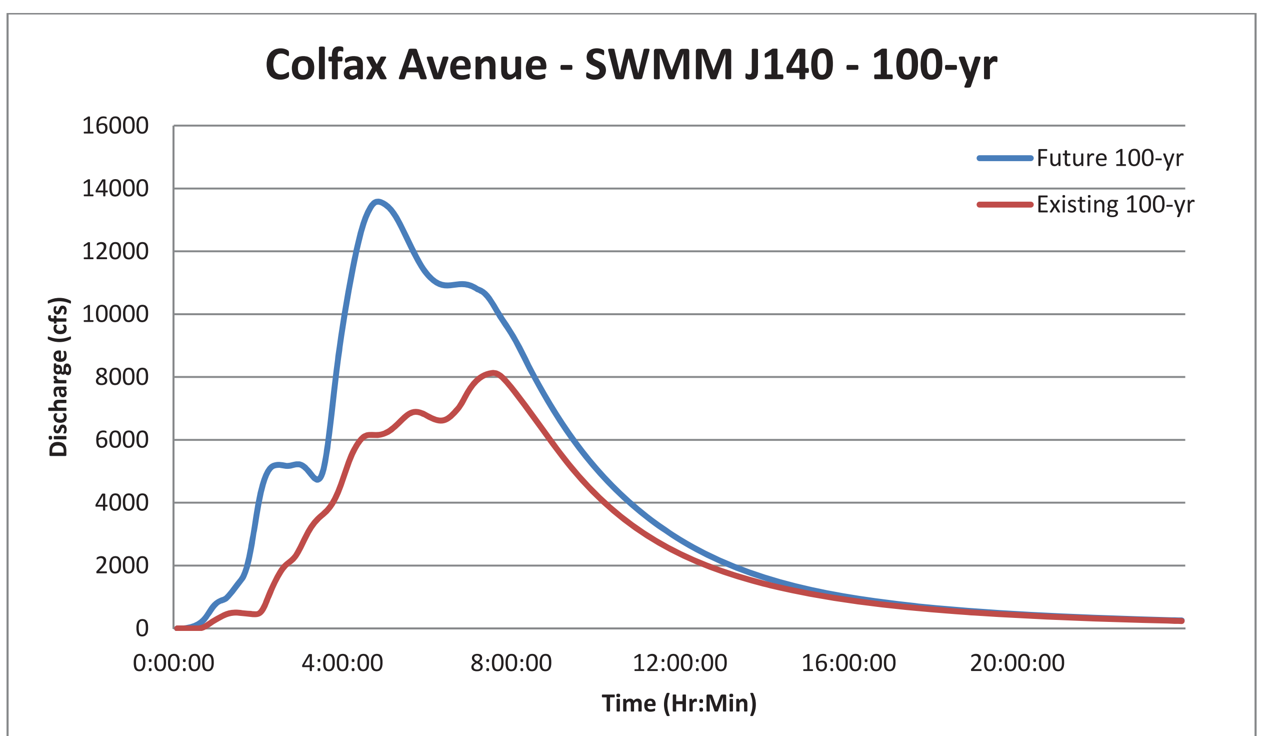
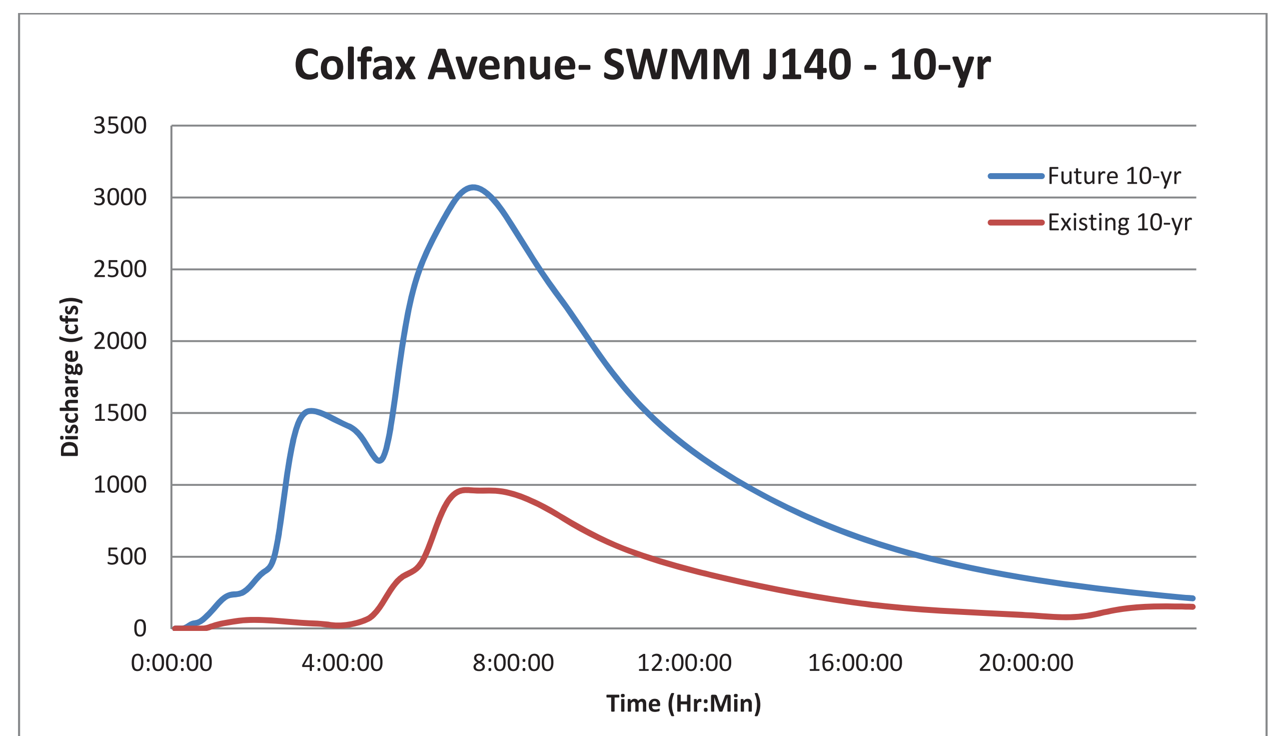
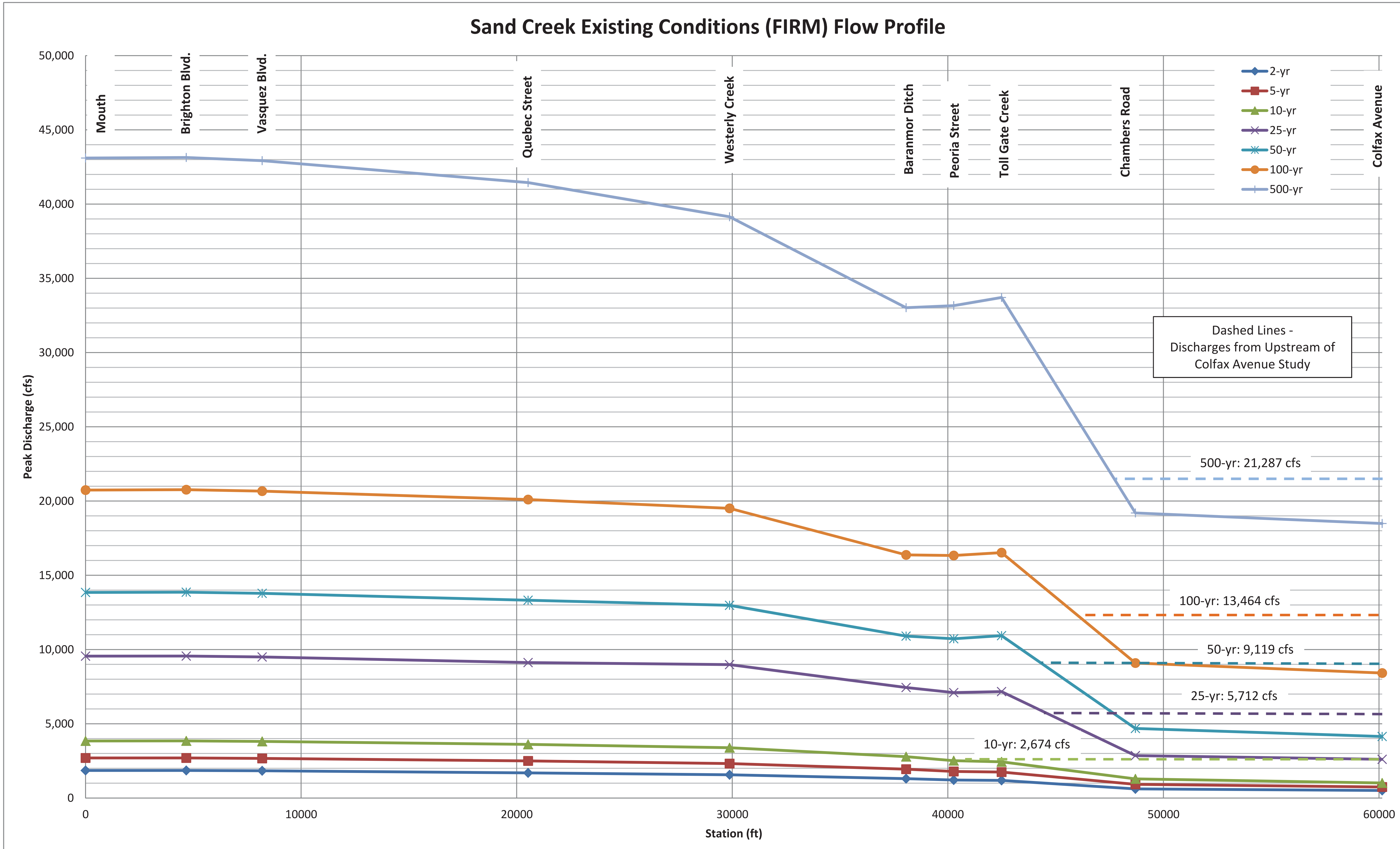
10- and 100-year Hydrographs

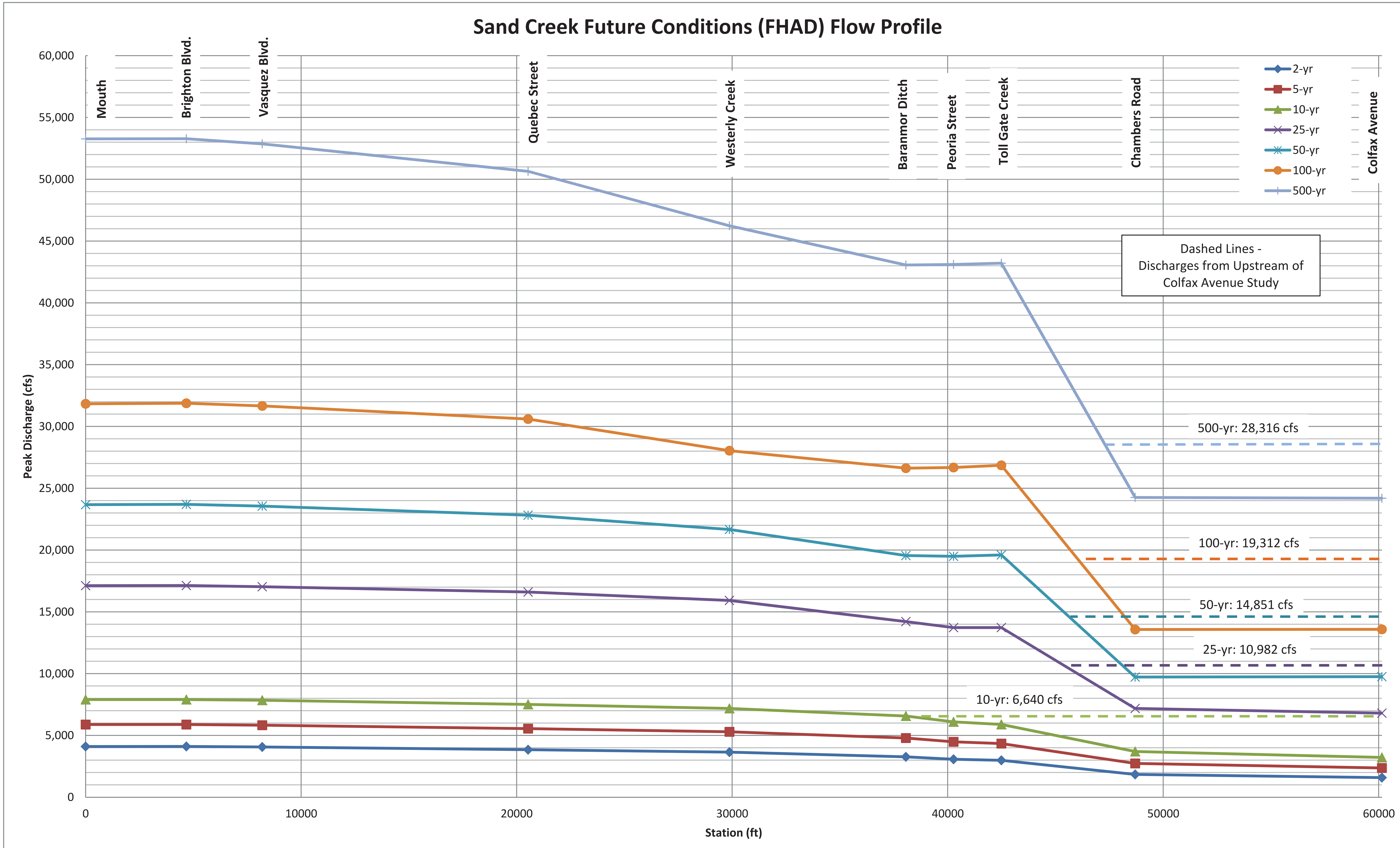









Sand Creek Existing Conditions (FIRM) Flow Profile
Peak Discharge (cfs)
Station (ft)
Mouth
Brighton Blvd.
Vasquez Blvd.
Quebec Street
Westerly Creek
Baranmor Ditch
Peoria Street
Toll Gate Creek
Chambers Road
Colfax Avenue
2-yr
5-yr
10-yr
25-yr
50-yr
100-yr
500-yr
Dashed Lines - Discharges from Upstream of Colfax Avenue Study
500-yr: 21,287 cfs
100-yr: 13,464 cfs
50-yr: 9,119 cfs
25-yr: 5,712 cfs
10-yr: 2,674 cfs
50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
0
10000
20000
30000
40000
50000
60000



Sand Creek Future Conditions (FHAD) Flow Profile
Peak Discharge (cfs)
Station (ft)
Mouth
Brighton Blvd.
Vasquez Blvd.
Quebec Street
Westerly Creek
Baranmor Ditch
Peoria Street
Toll Gate Creek
Chambers Road
Colfax Avenue
2-yr
5-yr
10-yr
25-yr
50-yr
100-yr
500-yr
Dashed Lines - Discharges from Upstream of Colfax Avenue Study
500-yr: 28,316 cfs
100-yr: 19,312 cfs
50-yr: 14,851 cfs
25-yr: 10,982 cfs
10-yr: 6,640 cfs

SWMM Node	SWMM Peak Discharge (cfs)													
	Existing Conditions							Future Conditions						
	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	500-yr	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	500-yr
B010	70	98	124	224	272	349	544	131	182	225	430	516	623	871
B020	233	324	403	819	1,014	1,392	2,153	436	597	734	1,465	1,756	2,121	2,979
B030	187	267	338	584	740	986	1,699	437	614	771	1,398	1,699	2,132	3,162
B040	104	151	191	403	548	751	1,169	214	303	386	733	906	1,143	1,638
B050	68	99	142	361	486	670	1,042	112	159	217	491	635	844	1,268
B060	42	60	90	230	333	482	790	127	180	229	483	625	825	1,235
B070	10	14	18	46	62	107	222	55	78	99	181	225	313	513
Baranmor_Ditch	114	171	221	376	463	606	995	177	241	291	542	682	893	1,359
J010	1,855	2,696	3,844	9,562	13,861	20,764	43,138	4,106	5,880	7,903	17,131	23,697	31,876	53,278
J020	1,833	2,666	3,810	9,499	13,783	20,671	42,928	4,064	5,828	7,844	17,031	23,557	31,662	52,864
J030	1,690	2,497	3,609	9,119	13,319	20,100	41,450	3,845	5,550	7,506	16,600	22,817	30,600	50,638
J040	1,562	2,321	3,386	8,983	12,979	19,510	39,148	3,646	5,291	7,185	15,924	21,663	28,040	46,236
J050	1,305	1,943	2,783	7,440	10,904	16,375	33,025	3,269	4,791	6,567	14,211	19,554	26,625	43,064
J060	1,213	1,790	2,512	7,100	10,727	16,332	33,159	3,074	4,483	6,098	13,721	19,490	26,675	43,103
J070	1,184	1,746	2,436	7,165	10,933	16,525	33,714	2,987	4,342	5,887	13,723	19,604	26,858	43,209
J080	619	935	1,313	2,932	4,769	9,133	19,384	1,860	2,753	3,720	7,285	9,712	13,551	24,132
J090	620	935	1,312	2,930	4,766	9,135	19,378	1,860	2,753	3,721	7,281	9,715	13,554	24,171
J100	614	920	1,289	2,856	4,686	9,089	19,200	1,846	2,732	3,695	7,185	9,721	13,570	24,255
J110	558	863	1,197	2,658	4,513	8,848	18,755	1,692	2,548	3,449	6,840	9,851	13,776	24,468
J120	555	856	1,185	2,625	4,473	8,798	18,646	1,676	2,523	3,427	6,791	9,740	13,562	24,174
J130	516	766	1,052	2,606	4,162	8,478	18,513	1,603	2,393	3,309	6,796	9,750	13,573	24,187
J140	506	739	1,012	2,607	4,140	8,415	18,488	1,588	2,363	3,218	6,800	9,754	13,582	24,194
J150	487	702	964	2,607	4,052	8,133	18,483	1,509	2,235	3,070	6,801	9,755	13,585	24,198
RightBankOSP_0301_0302	5	6	8	16	20	24	37	6	8	9	19	23	28	41
RightBankOSP_0701_0801	69	101	133	283	357	472	684	105	153	198	395	481	600	845
RightBankOSP_1001_1101	27	38	51	131	193	287	505	93	128	167	356	455	594	877
RightBankOSP_101	2	3	4	8	11	15	25	2	3	4	8	11	15	25
RightBankOSP_201	24	35	44	88	106	140	209	30	43	54	104	126	161	232
RightBankOSP_401	14	20	26	63	90	141	258	47	66	82	175	220	287	435
RightBankOSP_501	92	99	103	110	116	122	139	101	103	106	114	119	125	139
RightBankOSP_601	6	9	13	29	38	52	77	12	16	20	45	57	76	107
RightBankOSP_901	25	35	44	100	130	170	256	29	41	51	113	144	186	275
Sand_Creek	487	702	964	2,607	4,052	8,133	18,483	1,509	2,235	3,070	6,801	9,755	13,585	24,198
Toll_Gate_Creek	848	1,269	1,770	4,777	6,989	10,187	18,488	1,493	2,183	3,008	7,186	9,905	13,551	21,468
Toll_Gate_Creek_Spill	0	0	0	28	54	41	170	41	56	69	160	197	247	360
Westerly_Creek	404	582	797	1,888	2,444	3,290	5,369	404	582	797	1,888	2,444	3,290	5,369
B025_spill	0	0	0	0	0	298	1,059	0	0	0	0	163	566	1,400
Outfall	1,855	2,695	3,843	9,557	13,844	20,740	43,104	4,105	5,879	7,901	17,115	23,671	31,835	53,267
B025	180	259	360	837	1,097	1,468	2,229	257	366	486	1,047	1,333	1,736	2,570

SWMM Total Inflow (Ac.-ft.)														
	Existing Conditions							Future Conditions						
SWMM Node	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	500-yr	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	500-yr
B010	20.3	26.8	32.8	47.3	56.5	67.2	98.5	33.5	44.2	54.0	78.3	93.0	108.0	149.8
B020	59.8	79.2	97.0	145.2	176.5	219.1	325.3	98.2	129.8	159.0	232.0	276.2	322.2	448.1
B030	65.7	87.2	106.5	153.5	186.9	228.0	356.0	124.0	164.2	201.0	289.1	346.8	408.2	586.2
B040	38.1	50.3	61.4	99.1	126.4	159.0	242.1	65.4	86.5	106.2	158.7	192.1	227.7	322.2
B050	25.1	33.1	43.0	79.2	103.1	132.0	204.4	35.9	47.6	59.8	100.4	126.1	155.9	232.6
B060	17.4	23.0	30.5	57.7	79.5	106.2	170.6	40.2	53.1	65.4	103.4	128.6	157.1	231.4
B070	6.0	7.9	9.6	19.5	25.0	39.0	78.0	22.8	30.1	36.8	55.5	67.2	84.7	130.1
Baranmor_Ditch	36.5	48.5	59.8	88.4	112.9	139.6	212.7	52.2	68.4	83.5	125.5	154.1	185.7	266.4
J010	1,608.2	2,120.7	2,737.5	5,616.3	8,010.1	11,109.8	18,414.0	3,253.1	4,327.3	5,462.8	9,360.5	12,183.9	15,437.1	23,539.2
J020	1,586.7	2,093.1	2,703.8	5,554.9	7,948.7	11,048.4	18,321.9	3,222.5	4,265.9	5,401.4	9,299.1	12,061.2	15,345.0	23,385.8
J030	1,454.7	1,921.2	2,489.0	5,217.3	7,519.1	10,526.7	17,616.1	3,029.1	4,020.4	5,094.5	8,808.0	11,508.8	14,669.8	22,526.5
J040	1,341.2	1,770.8	2,304.8	4,910.4	7,181.5	10,097.0	16,971.6	2,829.6	3,744.2	4,757.0	8,347.7	10,925.6	13,994.6	21,575.1
J050	1,012.8	1,362.6	1,789.2	4,081.8	6,168.7	8,869.4	15,283.6	2,495.1	3,314.5	4,204.5	7,457.7	9,851.5	12,705.7	19,764.4
J060	948.3	1,279.8	1,684.9	3,928.3	5,953.9	8,623.9	14,854.0	2,406.1	3,191.8	4,081.8	7,212.2	9,575.3	12,368.1	19,273.3
J070	929.9	1,255.2	1,651.1	3,866.9	5,892.5	8,501.1	14,669.8	2,366.2	3,161.1	4,020.4	7,120.1	9,421.8	12,214.6	19,027.8
J080	491.0	675.2	920.7	2,406.1	3,836.3	5,739.0	10,158.4	1,586.7	2,111.5	2,700.7	4,879.7	6,537.0	8,562.5	13,472.9
J090	491.0	672.1	917.6	2,403.0	3,836.3	5,739.0	10,158.4	1,583.6	2,111.5	2,697.7	4,849.0	6,537.0	8,562.5	13,442.2
J100	484.9	662.9	905.4	2,384.6	3,805.6	5,708.3	10,127.7	1,574.4	2,099.2	2,685.4	4,849.0	6,506.3	8,531.8	13,411.5
J110	429.7	592.3	816.4	2,222.0	3,590.7	5,432.1	9,667.4	1,457.8	1,942.7	2,495.1	4,572.8	6,168.7	8,132.9	12,859.1
J120	429.7	589.2	810.2	2,212.7	3,590.7	5,432.1	9,606.0	1,445.5	1,927.3	2,473.6	4,542.1	6,138.0	8,071.5	12,767.0
J130	408.2	558.6	773.4	2,145.2	3,498.7	5,309.4	9,452.5	1,411.7	1,878.2	2,412.2	4,419.4	6,015.2	7,918.0	12,552.2
J140	402.0	549.4	761.1	2,129.9	3,498.7	5,278.7	9,421.8	1,402.5	1,869.0	2,400.0	4,419.4	5,984.6	7,887.3	12,521.5
J150	392.8	540.1	748.8	2,102.3	3,437.3	5,248.0	9,329.8	1,378.0	1,835.3	2,357.0	4,358.0	5,892.5	7,795.3	12,398.8
RightBankOSP_0301_0302	1.0	1.4	1.7	2.4	2.9	3.5	5.1	1.2	1.5	1.9	2.7	3.3	3.9	5.6
RightBankOSP_0701_0801	20.9	29.6	38.4	65.4	84.4	106.5	161.7	35.6	49.1	62.3	98.5	121.8	147.0	214.2
RightBankOSP_1001_1101	8.3	11.0	14.4	28.5	39.9	54.3	89.6	26.5	35.0	43.3	66.3	81.3	97.3	139.9
RightBankOSP_101	0.5	0.7	0.9	1.3	1.7	2.1	3.3	0.5	0.7	0.9	1.3	1.7	2.1	3.3
RightBankOSP_201	6.8	9.0	11.0	16.5	19.9	23.8	34.4	8.1	10.6	13.1	19.3	23.1	27.3	38.4
RightBankOSP_401	3.8	5.0	6.3	11.3	15.7	21.8	37.7	11.5	15.2	18.6	28.0	34.1	40.8	60.5
RightBankOSP_501	42.4	56.8	72.4	127.7	166.0	211.1	322.2	80.1	105.6	129.8	190.0	225.6	259.9	349.9
RightBankOSP_601	2.1	3.5	4.6	7.0	8.8	10.8	16.7	3.5	4.9	6.4	10.0	12.2	14.7	21.2
RightBankOSP_901	5.9	7.9	9.8	15.4	19.1	23.2	34.1	6.8	9.0	11.1	17.2	21.0	25.3	36.5
Sand_Creek	392.8	540.1	748.8	2,102.3	3,437.3	5,248.0	9,329.8	1,378.0	1,835.3	2,357.0	4,358.0	5,892.5	7,795.3	12,398.8
Toll_Gate_Creek	438.9	583.1	733.5	1,460.8	2,037.8	2,749.8	4,511.4	779.5	1,034.3	1,304.3	2,246.5	2,900.2	3,652.1	5,585.6
Toll_Gate_Creek_Spill	0.0	0.0	0.0	3.5	7.0	8.7	23.1	8.7	11.5	14.4	22.8	28.1	33.8	48.8
Westerly_Creek	285.7	343.7	435.8	712.0	871.6	1,040.4	1,439.4	259.6	343.7	435.8	712.0	871.6	1,040.4	1,424.0
B025_spill	0.0	0.0	0.0	0.0	0.0	13.4	85.3	0.0	0.0	0.0	0.0	6.0	33.1	118.8
Outfall	1,608.2	2,120.7	2,740.6	5,616.3	8,010.1	11,109.8	18,444.7	3,253.1	4,327.3	5,462.8	9,360.5	12,183.9	15,437.1	23,539.2
B025	63.2	83.5	106.5	184.8	235.7	294.0	445.0	82.2	108.9	136.0	221.3	275.0	334.5	494.1

SWMM Input / Output File

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EPA STORM WATER MANAGEMENT MODEL - VERSION 5.1 (Build 5.1.012)
--------------------------------------------------------------


*************
Element Count
*************
Number of rain gages ...... 0
Number of subcatchments ... 0
Number of nodes ........... 40
Number of links ........... 39
Number of pollutants ...... 0
Number of land uses ....... 0


************
Node Summary
************
                                       Invert      Max.    Ponded    External
Name                     Type           Elev.     Depth      Area    Inflow
-------------------------------------------------------------------------------
B010                 JUNCTION         5138.60    100.00       0.0
B020                 JUNCTION         5157.40    100.00       0.0
B030                 JUNCTION         5217.90    100.00       0.0
B035                 JUNCTION         5217.90    100.00       0.0
B040                 JUNCTION         5255.40    100.00       0.0
B050                 JUNCTION         5288.90    100.00       0.0
B060                 JUNCTION         5300.90    100.00       0.0
B070                 JUNCTION         5360.70    100.00       0.0
Baranmor_Ditch       JUNCTION         5288.90    100.00       0.0    Yes
J010                 JUNCTION         5138.50    100.00       0.0
J020                 JUNCTION         5157.30    100.00       0.0
J030                 JUNCTION         5217.80    100.00       0.0
J040                 JUNCTION         5255.30    100.00       0.0
J050                 JUNCTION         5288.80    100.00       0.0
J060                 JUNCTION         5300.80    100.00       0.0
J070                 JUNCTION         5311.00    100.00       0.0
J080                 JUNCTION         5326.70    100.00       0.0
J090                 JUNCTION         5339.60    100.00       0.0
J100                 JUNCTION         5360.60    100.00       0.0
J110                 JUNCTION         5385.10    100.00       0.0
J120                 JUNCTION         5393.50    100.00       0.0
J130                 JUNCTION         5398.90    100.00       0.0
J140                 JUNCTION         5401.00    100.00       0.0
J150                 JUNCTION         5419.10    100.00       0.0
RightBankOSP_0301_0302 JUNCTION         5360.70    100.00       0.0    Yes
RightBankOSP_0701_0801 JUNCTION         5393.60    100.00       0.0    Yes
RightBankOSP_1001_1101 JUNCTION         5401.10    100.00       0.0    Yes
RightBankOSP_101     JUNCTION         5326.80    100.00       0.0    Yes
RightBankOSP_201     JUNCTION         5339.70    100.00       0.0    Yes
RightBankOSP_401     JUNCTION         5360.70    100.00       0.0    Yes
RightBankOSP_501     JUNCTION         5360.70    100.00       0.0    Yes
RightBankOSP_601     JUNCTION         5385.20    100.00       0.0    Yes
RightBankOSP_901     JUNCTION         5399.00    100.00       0.0    Yes
Sand_Creek           JUNCTION         5419.20    100.00       0.0    Yes
Toll_Gate_Creek      JUNCTION         5313.00    100.00       0.0    Yes
Toll_Gate_Creek_Spill JUNCTION         5385.20    100.00       0.0    Yes
Westerly_Creek       JUNCTION         5255.40    100.00       0.0    Yes
B025_spill           OUTFALL          5261.00      0.00       0.0
Outfall              OUTFALL          5098.50     40.25       0.0
B025                 DIVIDER          5262.00    100.00       0.0


************
Link Summary
************
Name             From Node        To Node          Type            Length    %Slope Roughness
---------------------------------------------------------------------------------------------
L_B010           B010             J010             CONDUIT          100.0    0.1000    0.1000
L_B020           B020             J020             CONDUIT          100.0    0.1000    0.1000
L_B025           B025             J020             CONDUIT        10742.1    0.9747    0.0160
L_B025_spill     B025             B025_spill       CONDUIT          100.0    1.0001    0.1000
L_B030           B030             J030             CONDUIT          100.0    0.1000    0.1000
L_B035           B035             J030             CONDUIT          100.0    0.1000    0.0100
L_B040           B040             J040             CONDUIT          100.0    0.1000    0.1000
L_B050           B050             J050             CONDUIT          100.0    0.1000    0.1000
L_B060           B060             J060             CONDUIT          100.0    0.1000    0.1000
L_B100           B070             J100             CONDUIT          100.0    0.1000    0.1000
L_Baranmor_Ditch Baranmor_Ditch   J050             CONDUIT          100.0    0.1000    0.1000
L_RightBankOSP_1001 RightBankOSP_1001_1101 J140             CONDUIT          100.0    0.1000    0.1000
L_RightBankOSP_101 RightBankOSP_101 J080             CONDUIT          100.0    0.1000    0.1000
L_RightBankOSP_201 RightBankOSP_201 J090             CONDUIT          100.0    0.1000    0.1000
L_RightBankOSP_301 RightBankOSP_0301_0302 J100             CONDUIT          100.0    0.1000    0.1000
L_RightBankOSP_401 RightBankOSP_401 J100             CONDUIT          100.0    0.1000    0.1000
L_RightBankOSP_501 RightBankOSP_501 J100             CONDUIT          100.0    0.1000    0.1000
L_RightBankOSP_601 RightBankOSP_601 J110             CONDUIT          100.0    0.1000    0.1000
L_RightBankOSP_701 RightBankOSP_0701_0801 J120             CONDUIT          100.0    0.1000    0.1000
L_RightBankOSP_901 RightBankOSP_901 J130             CONDUIT          100.0    0.1000    0.1000
L_Sand_Creek     Sand_Creek       J150             CONDUIT          100.0    0.1000    0.1000
L_Toll_Gate_Creek Toll_Gate_Creek  J070             CONDUIT          100.0    2.0004    0.1000
L_Toll_Gate_Creek_Spill Toll_Gate_Creek_Spill J110             CONDUIT          100.0    0.1000    0.1000
L_Westerly_Creek Westerly_Creek   J040             CONDUIT          100.0    0.1000    0.1000
L010             J010             Outfall          CONDUIT         4673.0    0.6848    0.0500
L020             J020             J010             CONDUIT         3521.3    0.1363    0.0500
L030             J030             J020             CONDUIT        12336.0    0.1338    0.0500
L040             J040             J030             CONDUIT         9344.0    0.1017    0.0600
L050             J050             J040             CONDUIT         8187.6    0.0794    0.0500
L060             J060             J050             CONDUIT         2210.6    0.0905    0.0500
L070             J070             J060             CONDUIT         2217.7    0.0541    0.0500
L080             J080             J070             CONDUIT         3127.3    0.2782    0.0500
L090             J090             J080             CONDUIT         2367.8    0.2492    0.0500
L100             J100             J090             CONDUIT         3082.8    0.2595    0.0600
L110             J110             J100             CONDUIT         6827.2    0.2563    0.0600
L120             J120             J110             CONDUIT         1281.6    0.1092    0.0600
L130             J130             J120             CONDUIT         1696.1    0.2005    0.0600
L140             J140             J130             CONDUIT         1163.3    0.1805    0.0800
L150             J150             J140             CONDUIT          467.6    1.0907    0.0800
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*********************
Cross Section Summary
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Conduit	Shape	Full Depth	Full Area	Hyd. Rad.	Max. Width	No. of Barrels	Full Flow
L_B010	DUMMY	0.00	0.00	0.00	0.00	1	0.00
L_B020	DUMMY	0.00	0.00	0.00	0.00	1	0.00
L_B025	CIRCULAR	10.00	78.54	2.50	10.00	1	1326.54
L_B025_spill	DUMMY	0.00	0.00	0.00	0.00	1	0.00
L_B030	DUMMY	0.00	0.00	0.00	0.00	1	0.00
L_B035	DUMMY	0.00	0.00	0.00	0.00	1	0.00
L_B040	DUMMY	0.00	0.00	0.00	0.00	1	0.00
L_B050	DUMMY	0.00	0.00	0.00	0.00	1	0.00
L_B060	DUMMY	0.00	0.00	0.00	0.00	1	0.00
L_B100	DUMMY	0.00	0.00	0.00	0.00	1	0.00
L_Baranmor_Ditch	DUMMY	0.00	0.00	0.00	0.00	1	0.00
L_RightBankOSP_1001	DUMMY	0.00	0.00	0.00	0.00	1	0.00
L_RightBankOSP_101	DUMMY	0.00	0.00	0.00	0.00	1	0.00
L_RightBankOSP_201	DUMMY	0.00	0.00	0.00	0.00	1	0.00
L_RightBankOSP_301	DUMMY	0.00	0.00	0.00	0.00	1	0.00
L_RightBankOSP_401	DUMMY	0.00	0.00	0.00	0.00	1	0.00
L_RightBankOSP_501	DUMMY	0.00	0.00	0.00	0.00	1	0.00
L_RightBankOSP_601	DUMMY	0.00	0.00	0.00	0.00	1	0.00
L_RightBankOSP_701	DUMMY	0.00	0.00	0.00	0.00	1	0.00
L_RightBankOSP_901	DUMMY	0.00	0.00	0.00	0.00	1	0.00
L_Sand_Creek	DUMMY	0.00	0.00	0.00	0.00	1	0.00
L_Toll_Gate_Creek	DUMMY	0.00	0.00	0.00	0.00	1	0.00
L_Toll_Gate_Creek_Spill	DUMMY	0.00	0.00	0.00	0.00	1	0.00
L_Westerly_Creek	DUMMY	0.00	0.00	0.00	0.00	1	0.00
L010	L010	32.25	8601.75	18.24	446.10	1	146568.42
L020	L020	32.25	6927.75	16.30	352.10	1	48862.68
L030	L030	32.25	6927.75	17.54	352.10	1	50832.86
L040	L040	37.25	10125.00	20.43	467.10	1	59753.50
L050	L050	27.25	9118.00	10.39	622.10	1	36366.82
L060	L060	30.25	10755.75	17.21	600.10	1	64091.53
L070	L070	30.25	10755.75	13.25	600.10	1	41633.58
L080	L080	28.25	14923.00	14.54	888.10	1	139380.67
L090	L090	28.50	10751.75	12.70	678.10	1	86827.13
L100	L100	28.50	10751.75	14.05	678.10	1	78997.88
L110	L110	25.10	9125.50	15.32	580.10	1	70590.75
L120	L120	30.10	9863.50	17.21	595.10	1	53821.48
L130	L130	30.10	8875.75	14.58	610.10	1	58751.74
L140	L140	30.10	8875.75	15.99	610.10	1	44465.99
L150	L150	30.10	8875.75	16.37	610.10	1	110993.31

```
****************
Transect Summary
****************
**Transects omitted due to length**


*************************************************************
NOTE: The summary statistics displayed in this report are
based on results found at every computational time step,
not just on results from each reporting time step.
*************************************************************


****************
Analysis Options
****************
Flow Units ............... CFS
Process Models:
  Rainfall/Runoff ........ NO
  RDII ................... NO
  Snowmelt ............... NO
  Groundwater ............ NO
  Flow Routing ........... YES
  Ponding Allowed ........ NO
  Water Quality .......... NO
Flow Routing Method ...... KINWAVE
Starting Date ............ 01/01/2005 00:00:00
Ending Date .............. 01/06/2005 00:00:00
Antecedent Dry Days ...... 0.0
Report Time Step ......... 00:05:00
Routing Time Step ........ 30.00 sec


*********************
Control Actions Taken
*********************
```

Flow Routing Continuity	Volume acre-feet	Volume 10^6 gal
Dry Weather Inflow	0.000	0.000
Wet Weather Inflow	0.000	0.000
Groundwater Inflow	0.000	0.000
RDII Inflow	0.000	0.000
External Inflow	15039.041	4900.696
External Outflow	15132.523	4931.159
Flooding Loss	0.000	0.000
Evaporation Loss	0.000	0.000
Exfiltration Loss	0.000	0.000
Initial Stored Volume	0.000	0.000
Final Stored Volume	2.900	0.945
Continuity Error (%)	-0.641	

```
*******************************
Highest Flow Instability Indexes
*******************************
All links are stable.


*************************
Routing Time Step Summary
*************************
Minimum Time Step           :    30.00 sec
```


ICON ENGINEERING, INC.

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Average Time Step           :    30.00 sec
Maximum Time Step           :    30.00 sec
Percent in Steady State     :     0.00
Average Iterations per Step :     1.00
Percent Not Converging      :     0.00
```

****
Node Depth Summary
****

Node	Type	Average Depth Feet	Maximum Depth Feet	Maximum HGL Feet	Time of Max Occurrence days hr:min	Reported Max Depth Feet
B010	JUNCTION	0.00	0.00	5138.60	0 00:00	0.00
B020	JUNCTION	0.00	0.00	5157.40	0 00:00	0.00
B030	JUNCTION	0.00	0.00	5217.90	0 00:00	0.00
B035	JUNCTION	0.00	0.00	5217.90	0 00:00	0.00
B040	JUNCTION	0.00	0.00	5255.40	0 00:00	0.00
B050	JUNCTION	0.00	0.00	5288.90	0 00:00	0.00
B060	JUNCTION	0.00	0.00	5300.90	0 00:00	0.00
B070	JUNCTION	0.00	0.00	5360.70	0 00:00	0.00
Baranmor_Ditch	JUNCTION	0.00	0.00	5288.90	0 00:00	0.00
J010	JUNCTION	17.67	35.22	5173.72	0 07:48	35.22
J020	JUNCTION	47.61	65.50	5222.80	0 07:39	65.50
J030	JUNCTION	32.14	53.14	5270.94	0 07:08	53.14
J040	JUNCTION	30.28	48.03	5303.33	0 06:37	48.03
J050	JUNCTION	13.02	30.35	5319.15	0 06:02	30.34
J060	JUNCTION	12.24	30.70	5331.50	0 05:55	30.70
J070	JUNCTION	8.91	21.72	5332.72	0 05:44	21.72
J080	JUNCTION	8.66	21.10	5347.80	0 05:42	21.09
J090	JUNCTION	14.79	28.14	5367.74	0 05:38	28.14
J100	JUNCTION	9.45	22.16	5382.76	0 05:29	22.16
J110	JUNCTION	10.08	26.85	5411.95	0 05:07	26.85
J120	JUNCTION	4.87	22.68	5416.18	0 05:01	22.68
J130	JUNCTION	3.33	22.64	5421.54	0 04:55	22.64
J140	JUNCTION	15.29	32.30	5433.30	0 04:51	32.30
J150	JUNCTION	2.29	19.30	5438.40	0 04:50	19.30
RightBankOSP_0301_0302	JUNCTION	0.00	0.00	5360.70	0 00:00	0.00
RightBankOSP_0701_0801	JUNCTION	0.00	0.00	5393.60	0 00:00	0.00
RightBankOSP_1001_1101	JUNCTION	0.00	0.00	5401.10	0 00:00	0.00
RightBankOSP_101	JUNCTION	0.00	0.00	5326.80	0 00:00	0.00
RightBankOSP_201	JUNCTION	0.00	0.00	5339.70	0 00:00	0.00
RightBankOSP_401	JUNCTION	0.00	0.00	5360.70	0 00:00	0.00
RightBankOSP_501	JUNCTION	0.00	0.00	5360.70	0 00:00	0.00
RightBankOSP_601	JUNCTION	0.00	0.00	5385.20	0 00:00	0.00
RightBankOSP_901	JUNCTION	0.00	0.00	5399.00	0 00:00	0.00
Sand_Creek	JUNCTION	0.00	0.00	5419.20	0 00:00	0.00
Toll_Gate_Creek	JUNCTION	0.00	0.00	5313.00	0 00:00	0.00
Toll_Gate_Creek_Spill	JUNCTION	0.00	0.00	5385.20	0 00:00	0.00
Westerly_Creek	JUNCTION	0.00	0.00	5255.40	0 00:00	0.00
B025_spill	OUTFALL	0.00	0.00	5261.00	0 00:00	0.00
Outfall	OUTFALL	10.48	23.63	5122.13	0 07:56	23.63
B025	DIVIDER	0.25	7.30	5269.30	0 01:09	7.30

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Node Inflow Summary
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Node	Type	Maximum Lateral Inflow CFS	Maximum Total Inflow CFS	Time of Max Occurrence days hr:min	Lateral Inflow Volume 10^6 gal	Total Inflow Volume 10^6 gal	Flow Balance Error Percent
B010	JUNCTION	471.63	471.63	0 01:05	27.7	27.7	0.000
B020	JUNCTION	1741.35	1741.35	0 01:05	87.2	87.2	0.000
B030	JUNCTION	1467.79	1467.79	0 01:25	99.8	99.8	0.000
B035	JUNCTION	1116.84	1116.84	0 01:15	65.7	65.7	0.000
B040	JUNCTION	1087.91	1087.91	0 01:20	70.7	70.7	0.000
B050	JUNCTION	678.70	678.70	0 01:20	43.3	43.3	0.000
B060	JUNCTION	645.36	645.36	0 01:20	42.1	42.1	0.000
B070	JUNCTION	239.76	239.76	0 01:35	23	23	0.000
Baranmor_Ditch	JUNCTION	892.68	892.68	0 01:30	60.5	60.5	0.000
J010	JUNCTION	0.00	17179.80	0 07:48	0	4.93e+003	0.000
J020	JUNCTION	0.00	17195.04	0 07:38	0	4.9e+003	0.000
J030	JUNCTION	0.00	17378.22	0 07:06	0	4.71e+003	0.000
J040	JUNCTION	0.00	17528.90	0 06:35	0	4.53e+003	0.000
J050	JUNCTION	0.00	17441.78	0 06:02	0	4.12e+003	0.000
J060	JUNCTION	0.00	17247.20	0 05:55	0	4.02e+003	0.000
J070	JUNCTION	0.00	17204.27	0 05:44	0	3.97e+003	0.000
J080	JUNCTION	0.00	13881.11	0 05:42	0	2.78e+003	0.000
J090	JUNCTION	0.00	13883.76	0 05:38	0	2.78e+003	0.000
J100	JUNCTION	0.00	13887.92	0 05:29	0	2.77e+003	0.000
J110	JUNCTION	0.00	13824.97	0 05:07	0	2.65e+003	0.000
J120	JUNCTION	0.00	13797.96	0 05:01	0	2.63e+003	0.000
J130	JUNCTION	0.00	13659.75	0 04:55	0	2.58e+003	0.000
J140	JUNCTION	0.00	13651.24	0 04:51	0	2.57e+003	-0.000
J150	JUNCTION	0.00	13584.86	0 04:50	0	2.54e+003	0.000
RightBankOSP_0301_0302	JUNCTION	28.01	28.01	0 00:45	1.26	1.26	0.000
RightBankOSP_0701_0801	JUNCTION	600.11	600.11	0 01:05	47.9	47.9	0.000
RightBankOSP_1001_1101	JUNCTION	593.89	593.89	0 01:10	31.7	31.7	0.000
RightBankOSP_101	JUNCTION	15.40	15.40	0 01:05	0.7	0.7	0.000
RightBankOSP_201	JUNCTION	161.18	161.18	0 01:05	8.89	8.89	0.000
RightBankOSP_401	JUNCTION	287.41	287.41	0 01:00	13.3	13.3	0.000
RightBankOSP_501	JUNCTION	124.79	124.79	0 03:20	84.7	84.7	0.000
RightBankOSP_601	JUNCTION	75.97	75.97	0 01:05	4.78	4.78	0.000
RightBankOSP_901	JUNCTION	185.80	185.80	0 00:55	8.23	8.23	0.000
Sand_Creek	JUNCTION	13584.86	13584.86	0 04:50	2.54e+003	2.54e+003	0.000
Toll_Gate_Creek	JUNCTION	13550.80	13550.80	0 02:05	1.19e+003	1.19e+003	0.000
Toll_Gate_Creek_Spill	JUNCTION	246.76	246.76	0 00:45	11	11	0.000
Westerly_Creek	JUNCTION	3289.96	3289.96	0 01:25	339	339	0.000
B025_spill	OUTFALL	0.00	315.08	0 01:30	0	4.74	0.000
Outfall	OUTFALL	0.00	17168.27	0 07:56	0	4.93e+003	0.000
B025	DIVIDER	1485.08	1485.08	0 01:30	96.6	96.6	0.000

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Node Flooding Summary

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No nodes were flooded.

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Outfall Loading Summary
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Outfall Node	Flow Freq Pcnt	Avg Flow CFS	Max Flow CFS	Total Volume 10^6 gal
B025_spill	0.73	201.04	315.08	4.737
Outfall	99.60	1530.51	17168.27	4926.056
System	50.17	1731.55	17168.27	4930.793

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Link Flow Summary
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Link	Type	Maximum |Flow| CFS	Time of Max Occurrence days hr:min	Maximum |Veloc| ft/sec	Max/ Full Flow	Max/ Full Depth
L_B010	DUMMY	471.63	0 01:05			
L_B020	DUMMY	1741.35	0 01:05			
L_B025	CONDUIT	1179.33	0 02:04	19.57	0.89	0.73
L_B025_spill	DUMMY	315.08	0 01:30			
L_B030	DUMMY	1467.79	0 01:25			
L_B035	DUMMY	1116.84	0 01:15			
L_B040	DUMMY	1087.91	0 01:20			
L_B050	DUMMY	678.70	0 01:20			
L_B060	DUMMY	645.36	0 01:20			
L_B100	DUMMY	239.76	0 01:35			
L_Baranmor_Ditch	DUMMY	892.68	0 01:30			
L_RightBankOSP_1001	DUMMY	593.89	0 01:10			
L_RightBankOSP_101	DUMMY	15.40	0 01:05			
L_RightBankOSP_201	DUMMY	161.18	0 01:05			
L_RightBankOSP_301	DUMMY	28.01	0 00:45			
L_RightBankOSP_401	DUMMY	287.41	0 01:00			
L_RightBankOSP_501	DUMMY	124.79	0 03:20			
L_RightBankOSP_601	DUMMY	75.97	0 01:05			
L_RightBankOSP_701	DUMMY	600.11	0 01:05			
L_RightBankOSP_901	DUMMY	185.80	0 00:55			
L_Sand_Creek	DUMMY	13584.86	0 04:50			
L_Toll_Gate_Creek	DUMMY	13550.80	0 02:05			
L_Toll_Gate_Creek_Spill	DUMMY	246.76	0 00:45			
L_Westerly_Creek	DUMMY	3289.96	0 01:25			
L010	CHANNEL	17168.27	0 07:56	9.86	0.12	0.48
L020	CHANNEL	17177.72	0 07:48	5.66	0.35	0.66
L030	CHANNEL	17132.82	0 07:39	5.66	0.34	0.66
L040	CHANNEL	17240.35	0 07:08	3.91	0.29	0.67
L050	CHANNEL	17056.06	0 06:37	3.88	0.47	0.77
L060	CHANNEL	17234.17	0 06:02	3.59	0.27	0.67
L070	CHANNEL	17172.91	0 05:55	3.09	0.41	0.72
L080	CHANNEL	13869.01	0 05:50	5.63	0.10	0.43
L090	CHANNEL	13879.79	0 05:42	7.09	0.16	0.49
L100	CHANNEL	13863.67	0 05:38	6.19	0.18	0.53
L110	CHANNEL	13655.89	0 05:29	4.11	0.19	0.60
L120	CHANNEL	13790.64	0 05:07	3.67	0.26	0.66
L130	CHANNEL	13649.33	0 05:01	4.83	0.23	0.69
L140	CHANNEL	13642.74	0 04:55	3.40	0.31	0.75
L150	CHANNEL	13581.80	0 04:51	8.18	0.12	0.64

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Conduit Surcharge Summary
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No conduits were surcharged.

Analysis begun on: Thu Oct 19 17:40:10 2017
Analysis ended on: Thu Oct 19 17:40:11 2017
Total elapsed time: 00:00:01